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July 10, 2009

Ref. No: 09-6209-SC-91

Mr. Mark Purcell  
Superfund Division (6SF-RL)  
U.S. Environmental Protection Agency  
1445 Ross Avenue, Suite 1220  
Dallas, TX 75202

Re: Revised Submittal  
Site-Wide Supplemental Feasibility Study Part II  
Development and Screening of Remedial Alternatives  
United Nuclear Corporation's Church Rock Tailings Site, New Mexico  
Administrative Order (Docket No. CERCLA 6-11-89)

Dear Mr. Purcell:

On behalf of United Nuclear Corporation (UNC), Chester Engineers has prepared this report concerning UNC's mill tailings site near Gallup, New Mexico. This report addresses EPA's comments letter to UNC of November 22, 2006, regarding "N.A. Water Systems List of Preliminary Assembled Remedial Alternatives."

Please contact Mr. Roy Blickwedel (General Electric Corporation) at (610) 992-7935 if you have any questions or need additional information.

Sincerely,

A handwritten signature in black ink, appearing to read 'Mark Jancin', with a horizontal line extending to the right.

Mark Jancin, P.G.  
Project Manager

Enclosure (2 hard copies with pdf copy on CD inside the back cover)

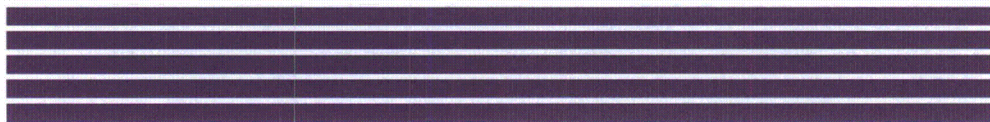
cc with enclosure: Yolande Norman, Nuclear Regulatory Commission (2 copies)  
Earle Dixon, New Mexico Environment Department  
Eugene Esplain, Navajo Nation Environmental Protection Agency  
Larry Bush, United Nuclear Corporation  
Roy Blickwedel, General Electric Corporation

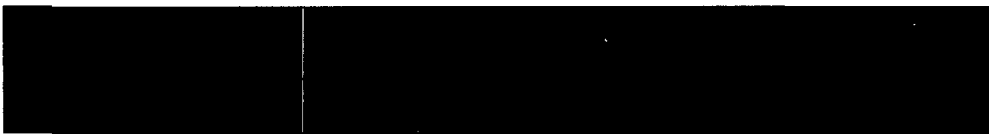


**Revised Submittal: Site-Wide  
Supplemental Feasibility Study Part II**

July 2009

United Nuclear Corporation  
Church Rock Tailings Site  
Church Rock, New Mexico





United Nuclear Corporation  
Church Rock Tailings Site  
Church Rock, New Mexico

**Revised Submittal: Site-Wide Supplemental Feasibility  
Study Part II**

July 2009

Prepared by: Mark D. Jancin, P.G.

Approved by: James A. Ewart, Ph.D., P.G.

Project No.: 09-6209-SC-91 (GE-CEP SWSFS)



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# Section 1

## *Introduction*

On behalf of United Nuclear Corporation (UNC), Chester Engineers is pleased to submit this revised review of the development and screening of remedial alternatives for the Church Rock mill tailings site. This document comprises Part II of the Site-Wide Supplemental Feasibility Study (SWSFS). A related, earlier document was submitted by UNC (N.A. Water Systems, September 25, 2006) and was titled "List of Preliminary Assembled Remedial Alternatives for the Site-Wide Supplemental Feasibility Study" (herein referred to as the "NAWS letter"). Please note that the groundwater group of N.A. Water Systems was purchased by Chester Engineers during December 2008.

Based on discussions between UNC and EPA, the Church Rock SWSFS will have the following three primary components:

- Remediation Standards Update = SWSFS Part I.
- Development and Screening of Remedial Alternatives = SWSFS Part II.
- Detailed Analysis of Remedial Alternatives = SWSFS Part III.

Part I was submitted to EPA in February 2007 (N.A. Water Systems, 2007); EPA provided UNC with comments on this submittal in a letter dated January 25, 2008. Those EPA comments were the subject of multiple subsequent conference calls between UNC, EPA, the Nuclear Regulatory Commission (NRC), the New Mexico Environment Department (NMED), and the Navajo Nation Environmental Protection Agency (NNEPA).

EPA indicated that Part I should be revised satisfactorily by UNC prior to UNC proceeding with further development of Part II. Part I revisions required substantial new development of statistical calculations using EPA's preferred ProUCL statistical software package. Revisions to Part I included UNC submittals to EPA regarding the following regulatory and technical issues:

- Compilation of contaminant-specific groundwater cleanup levels and other comparison values (including Record of Decision (ROD; EPA, 1988c) cleanup levels and changes in potential applicable or relevant and appropriate requirements (ARARs); current EPA primary drinking water standards; NRC License compliance standards; New Mexico Water Quality Control Commission standards; select background water quality concentrations; and current health-based criteria). UNC submitted this to EPA in October 2008 as Table 6 in the revised statistics Objective 1 submittal by N.A. Water Systems (2008b); this same compilation is provided in the present document as Table 1.
- Calculations of background water quality statistics for all three site hydrostratigraphic units (revised statistics Objective 1 submittal to EPA in October 2008 (N.A. Water Systems, 2008b)).
- Calculations of UCL95 (upper confidence limit on the mean at the 95% confidence level) statistics and exposure point concentrations for all three site hydrostratigraphic units (revised statistics Objective 2 submittal to EPA in December 2008 (N.A. Water Systems, 2008c)).

In a letter of February 11, 2009, EPA notified UNC that the submitted revisions to the SWSFS Part I were acceptable. EPA specified that the entire revised Part I did not need to be resubmitted at that time, but that it should be incorporated into the pending submittal of the entire SWSFS document. EPA also stated that UNC should proceed with further development of Part II, which is the subject of the present report.

Due to the specific nature of some of EPA's comments on Parts I and II, there is some topical overlap between UNC's submitted revisions to Part I and the revisions to Part II that are presented here. To address EPA's comments on UNC's preliminary submittal of Part II (the NAWS letter of September 2006) both specifically and comprehensively, UNC has developed the next two sections of this report in the format of a comment-and-response document. To aid the reader, each paragraph of each EPA comment has been identified with a sequential paragraph number within squared brackets.

## Section 2

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### USEPA General Comments of November 22, 2006

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#### 2.1 EPA General Comment 1

**EPA General Comment 1:** [1] *The NAWS letter summarizes two of the three phases of a feasibility study (FS): the development of alternatives and the screening of alternatives. Those alternatives that remain following the screening-out phase, if approved by EPA, are to be carried forward into the detailed analysis of alternatives, the last phase of the Feasibility Study (FS). Overall, the NAWS letter lacks sufficient information to allow EPA to fully assess the merits of the remedial alternatives developed and screened by UNC. It is recognized that UNC proposed to develop the SWSFS as a companion document to the EPA's original 1988 FS, and one that acknowledges and builds on that FS. However, the SWSFS still needs to represent a comprehensive study that is consistent with all relevant and current regulations and guidance on the performance of an FS and supports future EPA decision making.*

**UNC Response to General Comment 1:** UNC intends to prepare a SWSFS that is consistent with all relevant and current regulations and guidance on the performance of an FS. UNC also understands that the SWSFS will rely on and build upon previous determinations that were already established in the site FS and the ROD. The FS analysis, and the ROD determinations reached from that analysis, remain as valid as they were in 1988, as supported by nearly 20 years of operational and monitoring data that confirm the limitations that were forecast in the prior work. Nonetheless, the SWSFS will present a comprehensive review that is consistent with regulations and guidance and that supports EPA decision-making on the site.

#### 2.2 EPA General Comment 2

**EPA General Comment 2:** [1] *The NAWS letter appears to be out of sync with the 1988 Record of Decision (ROD) and the National Oil and Hazardous Substances Contingency Plan (NCP), 40 CFR 300 et seq., and it also fails to consult, discuss, or reference several important, relevant EPA Superfund guidance documents.*

[2] *First, the statement the NAWS will not second-guess matters in the 1988 FS that are EPA decision making is beside the point. The FS is not a decision-making document, but is instead a developmental document that develops, assembles, and analyzes various remedial alternatives, and it is pre-decisional. It is a foundation-source document, along with the Remedial Investigation (RI), for both the proposed plan and the ROD. The reason that EPA has directed the process now underway is because it wants to look at new potential remedial alternatives (and perhaps some old ones re-examined) for the Site in the light of several years of additional Site-related data that have been gathered during Site remediation and in light of possible additions to the body of scientific and engineering knowledge, as well as changes in potentially applicable or relevant and appropriate requirements (ARARs). In fact, this process arose out of the EPA's determination in the mandatory CERCLA five-year review of 2003 to engage in a Supplemental Feasibility Study (SFS), and it is consistent with the recognition in the 1988 ROD that it might be*



technically impracticable to clean up the ground water to meet all ARAR contaminant levels for ground water. See Appendix A to the 1988 ROD.

[3] The NAWS letter adopts an operable unit approach to UNC alternatives development, based on hydro-geologic strata, even though the EPA has never adopted this approach to Site ground-water remediation and has not directed it. While under the 1988 Memorandum of Understanding, the U.S. Nuclear Regulatory Commission (NRC) is responsible for remediation of the licensed facility or source control, EPA has handled the ground-water remediation problem as a single operable unit. See the selected alternative from the 1988 ROD. The SWSFS must look at the full range of comprehensive alternatives, individually or in combination, for a single ground-water remedy. The EPA recognizes that while it may be appropriate to examine and analyze different remedial approaches and technologies with respect to different saturated zones or geologic strata, remedial alternatives should be developed that deal comprehensively with the Site, including the no-action alternative.

[4] Further, the NAWS screening letter has missed the requirements of the NCP for the development and screening of remedial alternatives as a necessary precursor to the process of screening them. The NCP mandates development and analysis of preliminary remediation goals (PRGs), along with identification of potential ARARs, and analysis of systemic toxicants and known or suspected carcinogens, including contaminant risk pathways and receptors, as required underpinnings to the development, analysis, and screening of remedial alternatives. See 400 C.F.R. 300.430(e)(2). While it is true that PRGs from the original FS, as well as the remediation goals and remedial action objectives (RAOs) from the 1988 ROD, may still be valid (as UNC indicated in its July 27, 2006 letter to EPA), these issues need to be visited in the SFS process per the NCP. This has not been done even though for example, the five-year review identified at least nine compounds that should be examined for potential ARAR changes in light of regulatory developments since the 1988 ROD. The following list is taken from the 2003 Second Five-Year Review Report at p. 66:

- a. Arsenic – the arsenic MCL was to have been reduced to 0.010 mg/l, effective January 2006.
- b. Antimony – An MCL was promulgated for antimony (0.006 mg/l) in 1992.
- c. Beryllium – An MCL was promulgated for beryllium (0.004 mg/L) in 1992.
- d. Cadmium – The cadmium MCL was reduced to 0.005 mg/l in 1991.
- e. Thallium – An MCL was promulgated for thallium (0.002 mg/L) in 1992.
- f. Nitrate – The background value for nitrate was changed by the NRC to 190 mg/l on the basis of additional background studies it conducted in 1996. No decision has yet been made by the EPA on this change.
- g. Sulfate – The background value for nitrate was changed by the NRC to 2,215 mg/l on the basis of additional background studies it conducted in 1996. No decision has yet been made by the EPA on this change.

- h. *TDS – The background value for TDS was changed by the NRC to 4800 mg/l on the basis of additional background studies it conducted in 1996. No decision has yet been made by the EPA on this change.*
- i. *Uranium – The uranium MCL was reduced to 0.030 mg/l, effective December 2003.*

[5] *It is noted that the New Mexico Environment Department (NMED) supported the NRC's changes of the post-mining, pre-milling background levels for nitrate, sulfate and TDS in a letter to EPA, dated January 6, 1998. In its review of the referenced document, the NMED has indicated to EPA that it would reexamine the Site data (both the pre-1998 data submitted in support of the background revisions, as well as data that have been collected since 1998) before supporting the formal request for such background level revisions in the SWSFS. Additionally, as stated in NMED's January 6, 1998 letter, "UNC would also need to apply for a variance from applicable state ground water standards for the non-compliant constituents through the New Mexico Water Quality Control Commission (NMWQCC)." The NMED informed the EPA that it is not aware that this has yet been done.*

[6] *It is also noted that in revisiting the merits of existing RAOs and PRGs, including those health-based cleanup levels selected by EPA in the ROD, it may be necessary to reassess the risk at the Site based on current Site conditions. If this is deemed necessary, EPA will perform any reassessment of the risk, as appropriate.*

**UNC Response to General Comment 2 Paragraphs [1] and [2]:** UNC is following the NCP and EPA Superfund guidance. We are building upon the FS and ROD to evaluate remedial alternatives in light of site data and technology changes. We have also tabulated (Table 1) potential changes to ARARs.

The ROD is the current reference point by which any modifications to the remedy must be made. In as much as the remedy may be modified, such as through a ROD amendment, it is understood by UNC that the underlying site history, site characteristics, cleanup target areas and goals that were established in the ROD have not changed. In particular, where the more than 20 years of remedial action and monitoring support the fundamental findings of the 1988 ROD, we have taken care to preserve those findings. Appendix A of the ROD (EPA, 1988c) (Hydrologic Impact of Selected Remedy) contains one such fundamental finding which is consistent with the NCP and site data. It states the following under the section Contingencies for Selected Remedy:

The goal of the selected remedy is to restore groundwater outside the tailings disposal area to concentrations dictated by Federal and State standards, or background, to the maximum extent practicable and to the extent necessary to adequately protect public health and the environment. A program of regular performance evaluations, required as part of the selected remedy, will provide a measure of how well this remedial alternative meets modeling and design expectations. The performance evaluation program may indicate that the response objectives have been met and the remedy is complete. However, operational results may demonstrate that it is technically impractical to achieve all cleanup levels in a reasonable time period, and a waiver to meeting certain

contaminant-specific applicable or relevant and appropriate requirements (ARARs) may require re-evaluation as a result. Operational results may also demonstrate significant declines in pumping rates with time due to insufficient natural recharge of aquifers. The probability of significant reductions in the saturated thickness of aquifers at the site must be considered during performance evaluations since much of the water underlying the tailings disposal area is the result of mine water and tailings discharge, both of which no longer occur. In the event that saturated thicknesses cease to support pumping, remedial activity would be discontinued or adjusted to appropriate levels.

Since the issuance of the original EPA FS (1988b) and ROD (EPA, 1988c), quarterly groundwater monitoring has occurred for 20 years to date. Such monitoring has developed a very large body of site-wide water-quality and water-level data that are relevant to multiple issues to be addressed by the SWSFS. UNC discusses the meaning of these data in numerous reports (Earth Tech, 2000, 2002; GE, 2006; N.A. Water Systems, 2005, 2008d; Chester Engineers, 2009) that all point to a firm conclusion that it is technically impracticable to clean up the groundwater to meet all current ARAR contaminant levels for groundwater regardless of the technology applied.

**UNC Response to General Comment 2 Paragraph [3]:** UNC is treating groundwater as one operable unit in this document. As noted in EPA's comment, for this site it is appropriate to examine and analyze different remedial approaches and technologies with respect to different geologic strata. However, the remedial approaches are being developed in a way that will deal comprehensively with the site. In this document, UNC presents Figure 4, the assembled remedial alternatives, as a matrix similar to Table 8-1 (Combined Remedial Alternatives) in EPA's original FS (1988b). The original FS matrix, as is the one used in the SWSFS, is defined by rows of remedial alternatives and combined remedial alternatives specific to individual site hydrostratigraphic units (i.e., the Southwest Alluvium, Zone 3 and Zone 1), versus columns of the individual components of the combined remedial alternatives specific to individual site hydrostratigraphic units. We will evaluate whether the three different hydrostratigraphic units may require different remedial approaches to be effective.

**UNC Response to General Comment 2 Paragraphs [4] and [6]:** A compilation of contaminant-specific groundwater cleanup levels and other comparison values (including potential ARARs) has been accepted by EPA (see Table 6 of N.A. Water Systems, 2008b), as part of the revision of SWSFS Part I. This same compilation is provided in the present document as Table 1. All of the specific compounds and elements listed in this EPA comment are included in Table 1.

On February 7, 2007, UNC and EPA held a conference call concerning site risk assessment (EPA included a risk assessment specialist on the call). Key topics discussed included the following:

- Risk Assessment History at the Church Rock Site (including discussion of Chapter 4 of the EPA FS (1988b) – Public Health Assessment (PHA, discussed further below); the Agency for Toxic Substances and Disease Registry (ATSDR) Site Health Assessment (November 21, 1988); and the absence of ecological risk assessments having been completed because this is a groundwater-only site with no ecological receptor exposure)).
- Current Conditions (including discussion of changes in risk assessment methods over time; changes in toxicity factors; and other relevant considerations including the detection of significant radionuclide (e.g., uranium, radium-226, and radium-228) and inorganic constituent (e.g., arsenic, manganese, sulfate, and TDS) concentrations in background wells (e.g., Southwest Alluvium well SBL-1 and Zone 3 well NBL-1)).
- UNC's conclusions that: (1) risks will be similar if based on similar assumptions; (2) background water risk contributions will be significant; and (3) an updated risk assessment is unwarranted.

The following discussion elaborates on some of these issues including contaminant risk pathways and receptors, and a discussion of the key points presented in the original EPA (1988b) PHA.

### 2.2.1 Human Exposure Potential

For human health the following contaminant risk pathways were evaluated:

- Direct ingestion of groundwater.
- Dermal absorption of groundwater (e.g., through bathing).
- Ingestion of groundwater-irrigated produce.

There is no potential for human exposure to groundwater in the property owned by UNC (Sections 2 and 36), except during the quarterly groundwater sampling conducted by UNC personnel. No groundwater supply wells drawing on any of the three hydrostratigraphic units will be allowed on UNC property, and the same restriction will apply once this property is turned over to the Department of Energy for long-term surveillance monitoring.

EPA stated the following in the ROD about the inaccessibility and unsuitability of Zone 1 for water supply wells: "EPA studies indicate that the physical characteristics of Zone 1 are such that sufficient quantities of water could not be pumped from the sandstone to support volumes required for domestic or livestock purposes. Therefore, Zone 1 would not be a good candidate for locating a domestic or livestock well even if there were no impacts from tailings seepage" (ROD, EPA 1988c, Appendix H (Responsiveness Summary), Response to Comment 9 in Section 2, p. 4).

In the Southwest Alluvium outside the site boundary, there are no exceedances of hazardous constituents for which there are ROD-based standards or NRC License groundwater protection standards. Offsite impacted groundwater in the Southwest Alluvium has quality that is equal to

or better than the offsite background water quality; both types of groundwater are unsuitable for human consumption.

In Zone 3, the impacted groundwater is presently restricted to locations within the site property boundary (Sections 2 and 36). Zone 3 in Section 1 is predominantly unsaturated. A new set of Zone 3 extraction wells were brought online during February 2009 in an attempt to contain the northward advance of the impacted water in Section 36 (the approved work plan was presented in N.A. Water Systems, 2008a).

#### *2.2.2 Environmental Exposure Potential*

No site groundwater naturally discharges to any bodies of surface water. Current potential effects on the ecology are mainly from the discharge of pumped water from Zone 3, and purged water from quarterly groundwater sampling, into the evaporation ponds on the South Cell. Illegally grazing stock have occasionally consumed water here but site access is restricted according to the NRC License and key parts of the site fencing have recently been physically strengthened, which has decreased the rate of incursions.

#### *2.2.3 Consequences of Exposure*

The consequences of human exposure to the most contaminated site groundwater are discussed next. It should be noted that, both within and outside of the site property boundary, the background groundwater quality is not suitable for human consumption.

#### *2.2.4 Original Public Health Assessment*

EPA prepared a Public Health Assessment (PHA) of the UNC Church Rock site, which was published as Chapter 4 of the FS (EPA, 1988b). The ROD indicates that although there was no exposure at that time to local residents from ingestion of groundwater in domestic and livestock wells within four miles of the site, EPA concluded that adverse health or environmental hazards could result in the future if no action was taken to prevent exposure to groundwater contaminants found at the site. Since the issuance of the ROD, new or revised toxicity values, and health-based values, have only become more conservative. As a result, if the human health risk assessment were updated, the conclusion reached would remain the same given similar exposure assumptions.

The PHA conclusions are based on the assumed ingestion of groundwater at contaminant concentrations equal to those measured during the 1985 RI sampling events (see Tables 4 and 5 of the ROD), which included a few sampling locations within Section 2 in addition to those in Sections 1, 3, and 36. In the PHA, EPA indicated this assumption was conservative since dilution, dispersion, and natural attenuation were expected to occur if seepage continued to migrate downgradient from the site and would likely further reduce the concentration of contaminants from the concentrations assumed.

The PHA calculated quantitative potential future health risks for carcinogenic effects due to both radionuclides and non-radionuclides and for non-carcinogenic effects.

The PHA assessed exposure to non-carcinogens by comparing the estimated daily intake of four indicator constituents (cadmium, manganese, nickel, and selenium) to the reference dose (RfD) or Acceptable Intake for Chronic Exposure developed at the time of the assessment. The results of the PHA indicated that the potential non-carcinogenic hazard index was greater than one under the future exposure scenario, for both the mean and maximum indicator parameter concentrations for each hydrostratigraphic unit (see Table 2 below).

**Table 2**  
**PHA Hazard Index Values**

(Source: PHA in EPA Feasibility Study, 1988b)

| Hydrostratigraphic Unit | Mean Hazard Index Adult | Maximum Hazard Index Adult | Mean Hazard Index Child | Maximum Hazard Index Child |
|-------------------------|-------------------------|----------------------------|-------------------------|----------------------------|
| Southwest Alluvium      | 5.2                     | 16.2                       | 18.2                    | 56.8                       |
| Zone 3                  | 5.5                     | 34.5                       | 13.3                    | 120.7                      |
| Zone 1                  | 3.2                     | 13.1                       | 4.6                     | 11.5                       |

The PHA concluded that the potential risk associated with the use of groundwater from Zones 1 and 3 exceeded  $10^{-6}$  and the potential hazard quotient exceeded 1.0. If the risk assessment were to be updated using current data and methods, these conclusions would not change, primarily because toxicity values (i.e., reference doses) have become more conservative since the PHA was prepared.

Based on long-term monitoring data and improved understanding of the site, the hazard associated with certain site contaminants likely would be attributable to background conditions.

Table I of the PHA listed constituents comprising "on-site contamination" based on the RI. Table II of the PHA listed constituents comprising "off-site contamination" based on sampling of four domestic wells located within four miles of the UNC site.

Notwithstanding whether an updated risk assessment is necessary, it should be pointed out that there likely is no reasonably anticipated future exposure for the following reasons:

- There is no reasonably anticipated exposure to any of the seepage-impacted waters in Section 2, which will be included in the License and property transfer from UNC to DOE under UMTRCA Title II.

- There is no reasonably anticipated exposure to the portion of the Zone 3 plume that extends off the UNC property into Section 1 because there is currently less than 5 feet of saturation, which is gradually draining. (For example, well EPA-9 had a saturated thickness of 3.55 ft on October 13, 2008 (see Table 10 in Chester Engineers, 2009)). For this reason, NRC (1999) eliminated Section 1 as a point-of-exposure for Zone 3. The Zone 1 sandstone in Section 1 is entirely unsaturated approximately 800 feet to the east of the impacted water.

As stated in the PHA, background groundwater concentrations of certain contaminants (for example, combined radium) represent significant proportions of, or for some data exceed, those in impacted groundwater.

**UNC Response to General Comment 2 Paragraph [5]:** Regarding background water quality, all of the agency stakeholders have agreed to use the background values calculated in the revised SWSFS Part I (N.A. Water Systems, 2008b). It is noted here that the uranium background values determined solely by reference to statistical parameter estimates are inappropriate for application to the Southwest Alluvium because they do not take into consideration the role that geochemistry plays in influencing the spatial variation in background (GE, 2006).

We believe that UNC would not need to apply for variances through the State administrative process. CERCLA response actions are subject to substantive, not administrative, requirements (see the preamble to the proposed NCP (53 Fed. Reg. 51443)). EPA elaborated in 55 Fed. Reg. 8762 that this interpretation is most consistent with the terms of CERCLA and the goals of the statutes:

Moreover, Congress made clear in sections 121(d)(2) and (d)(4) that the "standards" or "requirement" of other laws that are ARARs should be applied to actions conducted on-site, and specifically provided in section 121(e)(1) that federal and state permits would not be required for such on-site response actions. These subsections reflect Congress' judgment that CERCLA actions should not be delayed by time-consuming and duplicative administrative requirements such as permitting, although the remedies should achieve the substantive standards of applicable or relevant and appropriate laws. . . . Accordingly, it would be inappropriate to formally subject CERCLA response actions to the multitude of administrative requirements of other federal and state offices and agencies.

UNC should not have to apply to a state agency for a variance from a CERCLA ARAR. The variance itself is an ARAR that can be applied to the site.

### 2.3 EPA General Comment 3

**EPA General Comment 3:** *[1] NAWS fails to note or analyze several relevant EPA guidance documents dealing with the subjects that it raises in its screening analysis. Instead, NAWS largely backs its conclusions with the prior recommendations of UNC counsel and contractors without analysis or support. The NAWS reference list contains only one reference to EPA*

guidance out of 17 references that are shown. That guidance has undergone important modification noted below that is not mentioned. Also, although Technical Impracticability (TI) Waivers are mentioned in the NAWS letter, there is no mention of the requirements of, nor any reference to, the EPA Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, September 1993, OSWER Directive 9234.2-25.

[2] The NAWS letter refers to remedy technologies (GRAs) that cost too much compared to their benefits, yet it does not reference the applicable costing guidance and cost benefit guidance, much less engage in analysis based on them. While the EPA 1988 RI/FS Guidance is referenced overall by NAWS, the section in that guidance dealing with costing is not referenced and has in any event been superseded by two other guidance documents not referenced here. These are: A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, (July 2000 OSWER Directive 9355.0-75, and Scoper's Notes – An RI/FS Costing Guide. Bring in a Quality RI/FS on Time and Within Budget, EPA/540/G-90/002, NTIS: PB90-258369INX. Together, these supersede Section 6.2.3.7 of the Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA – Interim Final, October 1988, EPA/540/G-89/004 (cited by NAWS).

[3] Further, there are at least two guidance documents germane to the development and screening of remedial alternatives that also summarize the general RI/FS Guidance requirements. These have not been cited by NAWS and they are: Getting Ready: Scoping the RI/FS (November 1989), OSWER 9355.3-01FS1, NTIS: PB90-274390INX, and The Feasibility Study, Development and Screening of Remedial Action Alternatives (November 1989), OSWER 9355.3-01FS3, NTIS: PB90-274416INX. For analysis farther down the RI/FS process there is The Feasibility Study, Detailed Analysis of Remedial Action Alternatives (March 1990), OSWER 9355.3-01FSF4, NTIS: PB90-272675INX.

[4] The NAWS letter suggests consideration of Alternate Concentration Limits (ACLs). ACLs are governed by the NCP at 40 C.F.R. 300.430(e)(2)(i)(F) and the statute at 42 U.S.C. §9621(d)(2)(B)(ii). However, the analysis required by those provisions is not present, nor is a reference to, or explanation of, the provisions of EPA guidance relating to the use of ACLs for Superfund sites. That EPA guidance is: Alternate Concentration Limits (ACL's) in Superfund Cleanups, July 19, 2005, OSWER Directive 9200.4-39, 4 p. That guidance supersedes 1987 Resource Conservation and Recovery Act Interim Final ACL Guidance with respect to Superfund cleanups.

[5] All of these guidance documents are available in PDF file download on the EPA Headquarters web site for Superfund. In addition, under "technology considerations" on the EPA Superfund web site, there are a number of technology documents available as well as links to information sources on both commonly use and innovative technologies for Superfund sites.

**UNC Response to General Comment 3 Paragraph [1]:** We have reviewed EPA's cited guidance document on TI, as well as the following EPA TI guidance document: EPA Memorandum, January 19, 1995, Consistent Implementation of the FY 1993 Guidance on



Technical Impracticability of Ground-Water Restoration at Superfund Sites; OSWER Directive 9200.4-14. These references were used as appropriate in the analysis.

We have also reviewed the following relevant EPA information: EPA Power Point presentation, November 7, 2007, Technical Impracticability (TI) Waivers Usage at Superfund Sites; presented by Matt Charsky, Office of Superfund Remediation and Technology Innovation (OSRTI).

**UNC Response to General Comment 3 Paragraphs [2] and [3] and [5]:** We have reviewed all of EPA's cited guidance documents and relevant technology issues. These references were used as appropriate in the analysis.

**UNC Response to General Comment 3 Paragraph [4]:** We have reviewed EPA's cited regulations and guidance document on ACLs, as well as relevant regulations at 40 CFR §264.94(a) and (b). These references were used as appropriate in the analysis.

#### 2.4 EPA General Comment 4

**EPA General Comment 4:** *[1] In its June 23, 2006 letter to UNC, EPA specified that the analysis and data of UNC's previous TI evaluation shall be carried forward and discussed in the SWSFS if a TI Waiver is to be a component of any alternative. Although the TI Waiver is included in the list of alternatives carried through the development and screening process, the analysis and data supporting the TI Waiver alternative were not, nor was the guidance on evaluating TI in ground-water restoration discussed or referenced (see EPA General Comment No. 2, above). As UNC is aware, the EPA put together a TI Waiver Review Team for evaluating the merits of invoking a TI Waiver for the standards of sulfate, TDS and manganese based on previous Site-related documents submitted by UNC. The SWSFS shall be included in the set of documents that the TI Waiver Review Team will review in performing such evaluation. Therefore, the SWSFS needs to be conducted without an initial bias towards waiving ARARs. The SWSFS needs to include the TI evaluation and analysis and data to support carrying forward the TI Waiver into the detailed analysis of alternatives, but the discussion of such issues should follow only upon rigorous analysis of the possible effectiveness of all potential alternatives relative to Site-specific ARARs. This comment also pertains to the inclusion of ACLs as a component of any alternative.*

**UNC Response to General Comment 4:** During a conference call between UNC and EPA on December 19, 2006 (post-dating the EPA comments presently under review here), EPA requested that TI Waivers should be categorically eliminated as remedial alternatives during UNC's revision of SWSFS Part II. EPA suggested that instead, UNC might explain why some site constituents cannot meet ROD cleanup levels, potential ARARs, and other relevant comparison values. UNC has deleted reference to TI Waivers from the lists of remedial alternatives in this revision of SWSFS Part II. The SWSFS will reference and/or include the data and analyses that have previously been used to support former TI evaluations.

**2.5 EPA General Comment 5**

**EPA General Comment 5:** [1] *All cost documentation referenced in the MWH Supplemental FS (October 2004) should be included in the SWSFS.*

**UNC Response to General Comment 5:** This information is provided in Appendix C of the document.

**2.6 EPA General Comment 6**

**EPA General Comment 6:** [1] *The passive reactive barrier (PRB) alternative apparently was not evaluated for any of the aquifers. Please include the PRB alternative in the evaluation.*

**UNC Response to General Comment 6:** UNC has included permeable reactive barriers in the present evaluation (see Table 3 and Figure 1).

## Section 3

### **USEPA Specific Comments of November 22, 2006**

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#### **3.1 EPA Specific Comment 1**

**EPA Specific Comment 1:** *Page 7, paragraph 6: The document states that “Government parties have agreed that there is no Zone 3 point-of-exposure (POE) in Section 1 (NRC, September 16, 1999).” The NMED does not support the NRC concept of point-of-exposure for the protection of the State of New Mexico’s ground-water resources. The NMWQCC regulations and the NMED policy require groundwater to meet established standards throughout the aquifer, including beneath the contaminant source area(s), not only at designated locations such as POE wells. Please delete or revise any statements in the referenced document that refer to POE.*

**UNC Response to Specific Comment 1:** The compliance concept and phrase “point of exposure” is not used in the body of this revised submittal of SWSFS Part II. Nonetheless, the ROD expressly states that, “the selected remedy for this operable unit is designed to contain, remove, and evaporate contaminated groundwater resulting from tailings seepage *outside of the tailings disposal area thus preventing further migration of seepage into the environment*” (italics added). It should be noted that NMED policy is not an ARAR. The state’s policy is clearly in conflict with both the objectives of the CERCLA action and the NRC Source Materials License, which has established points of compliance for meeting the groundwater protection standards.

#### **3.2 EPA Specific Comment 2**

**EPA Specific Comment 2:** *Figure 1: The eleven process options referenced in the EPA’s 1988 FS should be listed in the table.*

**UNC Response to Specific Comment 2:** The relevant figure in EPA’s 1988 FS is Figure 5-3 (Technical Implementability Screening of Process Options). Under the category Remedial Technology of Vertical Barriers in that figure, there are seven (not eleven) process options shown. These seven process options are now shown in the present document’s Figure 1; an additional process option, deep soil mixing, is also shown.

#### **3.3 EPA Specific Comment 3**

**EPA Specific Comment 3:** *Table 2, Southwest Alluvium Alternatives: This table lists alternatives that are retained after the initial screening process. Please retain the following remedial technologies in this table from Figure 1:*

- a. Barriers – physical barriers were screened out from Figure 1 based on the fact that pumping to avoid spillover is required. Please retain the physical barrier with pumping alternative.*
- b. Hydraulic flushing – this alternative was not screened out from Figure 1, yet was not retained as an alternative; please add it to Table 2.*

**UNC Response to Specific Comment 3:** In the attached revised Figure 1, we have retained the physical barrier with pumping alternative for the Southwest Alluvium. In the attached revised Table 4 (Summary of Potential Remedial Alternatives for the Southwest Alluvium [revised version of former Table 2]) we have included the hydraulic flushing alternative.

# Section 4

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## *Revised Submittal*

### *Site-Wide Supplemental Feasibility Study Part II*

### *Development & Screening of Remedial Alternatives*

#### *4.1 Introduction and Scoping the SWSFS*

The following published EPA guidance for the FS process and related issues has been incorporated into the evaluation of remedial alternatives presented here: EPA, 1988e; 1989a; 1989b; 1990a; 1990b; 2000a; and 2005.

Unlike the original FS (EPA, 1988b), the SWSFS does not need to be “built from the ground up.” For example, EPA guidance (1989a) on scoping the RI/FS indicates that the following scoping elements are either not germane or are already developed for the context of the Church Rock tailings site (these are listed below in the order presented in this EPA guidance document). Note that most elements related to the RI phase are not relevant for present purposes; instead, we are concerned with a supplementary FS phase:

- Conduct site kickoff meetings (oriented toward the RI; for our SWSFS, we have already had numerous submittals and conference calls to develop and guide the new FS scope and content).
- Evaluate existing data (development of our SWSFS has involved evaluating groundwater quality data reviewed during the original EPA RI work (1985 to 1987), and groundwater quality and water-level data from 1985 to present (N.A. Water Systems, 2008b)).
- Conduct site visit (not needed).
- Develop conceptual site model (conceptual site models for the evolution of the anthropogenic groundwater and tailings seepage impact have been developed for all three hydrostratigraphic units at the Church Rock site).
- Identify remedial action objectives and potential remedial alternatives (ROD cleanup levels, NRC License groundwater protection standards, potential ARARs including MCLs, and other comparison values have been presented during the revision of SWSFS Part I; Table 1 in the present document shows the result of this compilation. Potential remedial alternatives will be further developed and screened in this revised SWSFS Part II).
- Initiate identification of potential ARARs (see Table 1 in the present document).
- Identify initial data needs and data quality objectives (not needed).
- Scoping deliverables (the planned contents of the three parts of the SWSFS have been described earlier in this document).
- Work plan (not needed for SWSFS).
- Sampling and analysis plan (not needed for SWSFS).
- Health and safety plan (not needed for SWSFS).

## **Section 4 SWSFS Part II, Development & Screening of Remedial Alternatives**

- Community relations plan (this is in the purview of EPA).

### **4.2 SWSFS II – Development & Screening of Remedial Action Alternatives**

It is important to keep in mind that the Church Rock tailings SWSFS deals solely with groundwater impacts in areas outside of Section 2, following the explicit focus of the original FS (EPA, 1988b, see their Figure ES-1).

EPA (1989b) concisely summarized the key steps in the development and screening of FS remedial action objectives. The key steps are summarized below in the order in which they are presented in this EPA guidance document, and the relevant components of the revised SWSFS Part II are developed.

#### **4.2.1 Establish Remedial Action Objectives**

Remedial action objectives specify:

- The contaminant(s) and media of concern (the contaminants of concern are presented in Table 1; the medium of concern is groundwater).
- The exposure route(s) and receptor(s) (these issues have been developed earlier in this report in UNC Response to General Comment 2 Paragraphs [4] and [6]).
- The remediation goal(s) for each exposure route.

This third bullet point merits discussion for the SWSFS Part II. According to the U.S. Department of Energy (1997):

Remedial Action Objectives or final Remediation Goals (RGs) are media-specific cleanup goals for a selected remedial action. Remediation efforts would be considered complete and no further action would be necessary upon attainment of the Remediation Goals. Preliminary remediation goals (PRGs) are the initial or proposed cleanup goals developed to provide risk reduction targets. PRGs are refined into RGs during the course of the RI/FS process based on cost, technical feasibility, community acceptance, uncertainty in the baseline risk assessment, and other risk management considerations. In the ROD where final cleanup targets are documented, RGs may also be called “remediation levels. [40 CFR 300.430(f)]

Development of RGs constitutes a core component of the development and screening of potential remedial alternatives conducted in the FS. RGs can be qualitative statements or numerical values expressed as concentrations of a chemical in an environmental medium. Achieving the RGs in the remedial action should result in residual contamination levels that are protective of human health and the environment. [40 CFR 300.430(e)(2)(i)] RGs must be properly described in order to identify a set of potentially viable, remedial alternatives. The description should include: (1) contaminants of concern, (2) exposure routes and receptors, and (3) acceptable contaminant levels for each exposure route.

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Numerical RGs are generally not required or applicable for alternatives that employ containment or engineered barrier technologies.

Site contaminant-specific groundwater cleanup levels and other comparison values, including promulgated standards, are presented in Table 1. The comparison values highlighted with green in Table 1 are those values that were used as comparative benchmarks in the statistical analysis of background water quality presented in N.A. Water Systems (2008b). The highlighted green values were selected in consultation with EPA and they represent a combination of the following: (1) ROD-derived cleanup levels; (2) NRC License compliance standards; (3) New Mexico WQCC standards (assigned variously as human health standards, irrigation standards, or other domestic water supply standards); and (4) EPA primary drinking water standards.

The green highlighted values in Table 1 were developed at EPA's request to provide comparison values for the background water quality statistical work – they are not legally enforceable. EPA's Five-Year Review Reports (including the one issued in September 2008) have stated that the site remedy is presently protective. EPA and the regulated community have interpreted 40 CFR 300.430(f)(1)(ii)(B) and (B)(1) to mean that ARARs are frozen as of the date of the ROD (also see 55 Fed. Reg. 8758). EPA is not required to adopt newly adopted standards.

UNC concludes that it is inappropriate for UNC to determine that the highlighted green values represent the remediation (cleanup) goals at this time. It is UNC's understanding that EPA reserves the authority to make decisions on whether to adopt new cleanup goals. Only EPA can issue ROD amendments specifying any modifications to their existing site cleanup goals. EPA has stated that they will address such decision-making after their review of the pending submittal of the complete SWSFS.

This status creates uncertainty in developing the SWSFS Part II, because specific cleanup goals are often tied to the FS development and screening of remedial action alternatives. The related uncertainty for UNC applies to both contaminant-specific and location-specific cleanup goals.

UNC is not in a position to determine any possible future changes to specific remedial (cleanup) goals; EPA has requested that UNC not propose specific changes to cleanup goals in the SWSFS; and, this status hinders the FS-related development and screening of remedial alternatives. Regardless, for further development of SWSFS Part II, UNC assumes that the green highlighted values in Table 1 (flagged in a footnote as "comparison values") are one set of values by which the remedial alternatives can be compared. Existing ROD standards and other standards (e.g. the NRC license standards) constitute other sets of goals which may also be compared among the potential remedial alternatives.

### *4.2.2 Develop General Response Actions*

General response actions (GRAs) are selected to satisfy the remedial action objectives. GRAs may be combined to form alternative remedial actions.

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The extent of tailings seepage impact in each of the site hydrostratigraphic units during October 2008 is shown in Appendix A: Figure A.1 (the Southwest Alluvium), Figure A.2 (Zone 3), and Figure A.3 (Zone 1). All three of these figures are from the most recent annual report (Chester Engineers, 2009); refer to that report for discussion of the specific geochemical criteria used to delineate the extent of the impacts.

The area and volume of impacted groundwater in each hydrostratigraphic unit are, respectively: 2,916,800 ft<sup>2</sup> (67 acres) and 22,728,756 ft<sup>3</sup> (170,022,900 gallons) in the Southwest Alluvium; 2,694,700 ft<sup>2</sup> (62 acres) and 1,927,502 ft<sup>3</sup> (14,418,720 gallons) in Zone 3; and 478,750 ft<sup>2</sup> (11 acres) and 1,145,247 ft<sup>3</sup> (8,567,042 gallons) in Zone 1. The volumes of impacted groundwater have been calculated by integrating the saturated thickness over the entire impacted area to obtain the saturated volume, and then adjusting the saturated volume for the effective porosity. The effective porosities applied are as follows:

- (1) 0.31 (31%) in the Southwest Alluvium (mean of a range of 0.27 to 0.35; see Chester Engineers, 2009, Table 5 footnote);
- (2) 0.06 (6%) in Zone 3 (N.A. Water Systems, 2008a); and
- (3) 0.08 (8%) in Zone 1 (mean of a range 0.07 to 0.09; see N.A. Water Systems, 2008d, p. 3-2).

The comparison values are shown with green highlighting in Table 1. Table 3 shows the selected site GRAs for groundwater remediation. In addition, it should be noted that for all seepage-impacted areas outside of Section 2, attainment of the ROD cleanup goals for sulfate and TDS is not practicable via technology or engineering since all groundwater is in chemical equilibrium with gypsum (see discussion in the most recent site annual report by Chester Engineers, 2009). Such site-wide geochemical equilibrium has been demonstrated by conducting MINTEQ modeling and analyses for the Southwest Alluvium (Earth Tech, 2002, Figure 3-7), Zone 1 (Earth Tech, 2000, Figure 16), and Zone 3 (UNC, unpublished).

The guidance in EPA (1989b; p. 2) suggests that at this point in the FS developmental process one may address a preliminary list of action-specific ARARs. Action-specific ARARs set restrictions on particular remedial activities as related to the management of hazardous waste. Depending on the assembled list of remedial technologies, UNC may evaluate action-specific ARARs, if appropriate, in SWSFS Part III.

The GRAs shown in Table 3 are:

- No further action (except for long-term stewardship by the Department of Energy (DOE) under Title II of the Uranium Mill Tailings Radiation Control Act (UMTRCA)).
- Hydraulic containment with extraction and evaporation (this is most similar to the existing site remedy in Zone 3).
- Enhanced extraction (i.e., rapid dewatering).
- Physical barriers (vertical engineered physical barriers or hydraulic-injection barriers).



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- Permeable reactive barriers (e.g., funneling impacted groundwater through a reactive “gate” for passive in situ treatment).
- Hydraulic flushing with extraction and evaporation.
- Treatment (note that some of the GRAs must be packaged with potential treatment processes to be effective).
- Institutional Controls (ICs).
- Revised cleanup standards (contaminant-specific issues are specific to each hydrostratigraphic unit).
- Alternate Concentration Limits (ACLs) (or similar regulator decisions for constituents that have demonstrably attained concentrations that are As Low As Reasonably Achievable (ALARA)).

Regarding the GRA of physical barriers (but excluding hydraulic barriers), this category refers to vertical barriers for containment. In principle, such containment could address the contaminant sources (the tailings disposal cells) or contaminated groundwater located at some distance from the source areas.

Regarding the GRA of revised cleanup levels, summary results from the most recent statistical analysis of background water quality (N.A. Water Systems, 2008b) are provided in Appendix B of the present report. Appendix Tables B.1 and B.2 summarize the results for the Southwest Alluvium; Tables B.3 and B.4 for Zone 1; and Tables B.5 and B.6 for Zone 3.

### *4.2.3 Identify and Screen Appropriate Technologies*

The term “technology” refers to general categories of technologies, such as chemical treatment or capping. The term “technology process option” refers to specific alternative processes within each technology family, such as ion exchange or use of a soil clay cap (EPA, 1989b).

A list of potentially applicable technologies and technology process options, corresponding to the identified general response actions, is compiled and then reduced by evaluating the process options with respect to technical implementability. Existing information on technologies and site characterization data are used to screen out process options that cannot be effectively implemented at the site (EPA, 1989b). Process options and screening are provided in Figure 1 and will be discussed in detail in the next section of this report.

Table 3 shows the GRAs (first and second columns) and their associated groundwater remedial technologies (third column) and our first-cut conclusions about applicability and screening (fourth column). Explanatory features addressing Table 3 are discussed next.

MWH (2004) submitted a Supplemental FS for the Zone 3 hydrostratigraphic unit, within which they presented a list of eight main screened alternatives (see their page 1). Our initial screening process has retained the following four alternatives from the Supplemental FS for Zone 3: enhanced extraction; cut-off or containment wells; directional wells; and tunnels. A fifth

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alternative, in-situ chemical fixation, has been modified such that it combines both injection of alkalinity and extraction. The Zone 3 Supplemental FS correctly screened out in-situ chemical fixation without an extraction component because of effectiveness limitations. That analysis indicated concerns about well-fouling and secondary permeability changes that left open the likelihood of spreading out the seepage-impacted groundwater.

Such concerns may be dealt with by coordinating injection and extraction well systems much like an in-situ leach mining operation (this is one of the remedial technologies in Table 3 that is tied to the GRA of hydraulic flushing with extraction and evaporation). UNC conducted an in-situ alkalinity stabilization pilot study to evaluate the potential to enhance the ongoing Zone 3 remediation through the use of alkalinity injection wells combined with carefully controlled extraction pumping at the site.

The pilot study was initially designed to test the injection of alkalinity-rich groundwater from a non-impacted part of the Southwest Alluvium into the Zone 3 aquifer. The injected water (so-called "fixiviant") would flow through the Zone 3 formation to recovery wells where the fixiviant could be pumped to the surface for treatment and disposal. However, concerns were expressed by NMED that the groundwater from the Southwest Alluvium did not meet applicable groundwater standards for sulfate, total dissolved solids and manganese. Following the original submission of this pilot study (in October 2005) and subsequent discussions, NMED identified groundwater withdrawn from a formation below Zone 3 and the underlying Mancos Shale (the Westwater Canyon Formation), via the onsite Mill Well, as a potential alternative source of groundwater to use as the injection water. The pilot study approach was revised to include injection of the Mill Well water (amended with sodium bicarbonate to add alkalinity) into Zone 3.

The pilot study was conducted from October 24, 2006, to February 15, 2007. The observed injection and extraction rates were unexpectedly low. As a result, the estimated travel time between the injection and extraction wells became prohibitively low and the pilot test was terminated. Data obtained as part of the pilot study indicated that the mineral feldspar in the Zone 3 arkosic sandstone had been altered by the acidic tailings liquids, generating kaolinitic clay that significantly clogged pore spaces and reduced hydraulic conductivity. The pilot study indicated that it would take 10 times longer to accomplish remedy goals than had been hypothesized. Using what had been envisioned as an approximate 5 year remedy enhancement could actually take 50 years or more. Based on these results, the use of alkalinity rich solutions to remediate the Zone 3 impacted groundwater in-situ is not feasible (ARCADIS BBL, 2007).

Next we consider the case of "alkalinity amended injection-water flushing" of the Zone 1 unit. As with Zone 3, the low hydraulic conductivity of this bedrock is a significant impediment; it would prohibit the effective application of flushing. Flushing requires coordinating the flow rates of injection wells and extraction wells. The following issues are important to consider: (1) the requirement to keep all injection and extraction wellheads on UNC property; (2) the narrowness of the strip of land between the eastern edge of the Central Cell and the Section 1 boundary (approximately 125 ft measured along an east-west direction; see Appendix A Figure

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A.3); and (3) the groundwater flow direction is toward the north-northeast. Based on these spatial and technical considerations, UNC concludes that flushing of Zone 1 impacted water is not a feasible remedial option. This conclusion is consistent with the results of the recent attempt to create a flushing system in Zone 3 of the Gallup Sandstone. For these reasons, the GRA of hydraulic flushing with extraction and evaporation has been retained in Table 3 for further consideration only in the Southwest Alluvium.

We generally adopt the original 1988 FS conclusion that vertical physical barriers are not implementable at the site because of the depths of the hydrostratigraphic units. Physical barriers are not implementable for Zone 1 and Zone 3 because of their depths and because they are bedrock; however, they may be implementable in downgradient locations of the Southwest Alluvium (discussed more below). For this reason, physical barriers are screened out for Zone 1 and Zone 3 at this stage while they are retained for the Southwest Alluvium (see the right-most column of Table 3). Hydraulic barriers (or hydraulic “fences”) are retained for consideration.

Permeable reactive barriers (PRBs) generally involve filling trenches with permeable reactive materials that clean up pollution through different methods by the following processes: (1) trapping or sorbing chemicals on their surface; (2) precipitating chemicals that are dissolved in water; (3) changing the chemicals into harmless ones; or (4) encouraging microbes in soil to metabolize the chemicals (EPA, 2001).

The GRA of PRBs has been reviewed in the following information sources: Blowes and others, 1997; NATO, 1998; Tri-Agency Permeable Reactive Barrier Initiative, 2002; Naval Facilities Engineering Command, 2002; EPA, 1998a, 1998b, 1999, 2000b, 2001, 2002, and 2007; the EPA Technology Innovation Program website at:

[http://www.clu-in.org/techfocus/default.focus/sec/Permeable\\_Reactive\\_Barriers%2C\\_Permeable\\_Treatment\\_Zones%2C\\_and\\_Application\\_of\\_Zero-Valent\\_Iron/cat/Overview/](http://www.clu-in.org/techfocus/default.focus/sec/Permeable_Reactive_Barriers%2C_Permeable_Treatment_Zones%2C_and_Application_of_Zero-Valent_Iron/cat/Overview/)

and the Remediation Technologies Development Forum (RTDF) website at:

<http://www.rtdf.org/public/permbarr/prbsumms/default.cfm>

These reviews include both groundwater pilot-scale demonstration projects and full-scale case studies.

According to EPA (2001; p.2), PRBs work best at sites with loose, sandy soil and a steady flow of groundwater; the pollution should be no deeper than 50 feet. In all the case studies we have reviewed, the reactive materials have been placed within unconsolidated materials overlying bedrock. Based on the total number of installations, most full-scale and pilot-scale implementations of PRBs have targeted contamination by chlorinated solvents.

EPA (2000b) and the RTDF website summarized the following case studies at former uranium mill and tailings sites:

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- Former mill site, Monticello, Utah – Full-scale PRB installed 1999; reactive medium zero-valent iron ( $\text{Fe}^0$ ); contaminants: uranium, arsenic, manganese, selenium, and vanadium – physical installation involved driving sheet piling into uppermost bedrock (depth not stated) forming a rectangular box; the native soils within the box were then replaced with  $\text{Fe}^0$  and gravel. The influent groundwater concentrations for the target contaminants were as follows: uranium (700 ug/L); selenium (40 ug/L); vanadium (400 ug/L); and arsenic (10 ug/L). Measurements of groundwater quality within the PRB showed nondetects for all these contaminants.
- Bodo Canyon Disposal Cell Mill Tailings Site, Durango, Colorado – Four pilot-scale PRBs installed from 1995 to 1999; four gates with reactive media of iron foam ( $\text{Fe}^0$ ), iron with copper catalyst, granular iron, and steel wool; contaminants: uranium, arsenic, selenium, zinc, radium-226, molybdenum, and manganese – physical installation collected ground seepage from a tailings disposal cell and piped it to a retention pond; PRBs were constructed to ~7 feet below ground in unconsolidated materials, in proximity to the retention pond – some pond fluids piped to holding tanks for testing of refined configurations of the reactive media. The influent concentrations of all the target contaminants were several orders higher than those associated with the Southwest Alluvium at the Church Rock site.
- Fry Canyon Uranium Mine Mill Tailings Site, Utah – Three pilot-scale PRBs installed 1997 – three gates with reactive media of amorphous ferric oxide, bone-char phosphate, and  $\text{Fe}^0$ ; contaminant: uranium – gates within an alluvial to colluvial aquifer (poorly sorted fine- and medium-grained sand) less than 10 feet thick. The influent concentration of uranium was not stated in the case study reviewed; however, that study does say that the phosphate and  $\text{Fe}^0$  barriers removed more than 99% of the uranium.

The RTDF website also summarized the following two full-scale case studies involving treatment for radionuclides at two other sites (these are not former mill and tailings sites):

- Y-12 Site, Oak Ridge National Laboratory, Oak Ridge, Tennessee – Liquid wastes stored in disposal ponds – one full-scale PRB installed 1997 and one full-scale continuous treatment trench installed 1997 – PRB gate reactive medium  $\text{Fe}^0$ ; continuous trench contains 5 separate reaction vessels – contaminants: nitric acid, uranium, and technetium – gate and trench within clay and regolith from 10 to 20 ft thick. The case study reviewed did not provide information on specific contaminant concentration reductions achieved by the PRBs.
- Rocky Flats Environmental Technology Site (Solar Ponds Plume), Golden, Colorado – Liquid wastes stored in a former pond have contaminated groundwater – one full-scale PRB installed 1999 – treatment via two reaction vessels with reactive media of  $\text{Fe}^0$  and wood chips – contaminants: nitrate and uranium -- the groundwater collection system intercepting the groundwater contaminant plume extends approximately 1,100 ft; to install the collection system, an excavation was dug at a variable depth of approximately

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20-30 ft below ground and approximately 10 ft into claystone. The influent concentration of uranium was 20-28 pCi/L; the PRB effluent concentration was <1 pCi/L.

All the above case examples involve PRBs configured as either funnel-and-gates or continuous treatment walls (or trenches), emplaced within unconsolidated materials at depths of 30 ft below ground or less.

The RTDF website describes the following case studies of PRBs targeting non-radionuclide inorganic constituents:

- Nickel Rim Mine Site, Sudbury, Ontario, Canada – Inactive mine tailings impoundment has contaminated groundwater (tailings have been undergoing oxidation for ~ 40 years) – one full-scale continuous PRB installed 1995 – reactive medium organic carbon – contaminants: nickel, iron, and sulfate – contaminated aquifer is 10-26 ft thick and composed of glacio-fluvial sand confined to a narrow valley bounded on both sides and below by bedrock; barrier formed by trenching spans the valley and is 50 ft long and 14 ft deep. The influent concentrations for the target contaminants were as follows: sulfate (2400-3800 mg/L); iron (740-1000 mg/L), and up to 10 mg/L of nickel. Treatment in the PRB caused a decrease in sulfate concentrations to 110-1900 mg/L; iron concentrations decreased to <1-91 mg/L; and dissolved nickel decreased to <0.1 mg/L.
- Tonolli Superfund Site, Nesquehoning, Pennsylvania – Former battery recycling and secondary lead smelting plant plus acid mine drainage from coal mine spoil – one full-scale continuous PRB installed 1998 – reactive medium limestone – contaminants: lead, cadmium, arsenic, zinc, and copper – contamination in coal mine spoil from 0-19 ft and in alluvium from 74-113 ft; PRB constructed by digging a trench 1,100 ft long and 20 ft deep (groundwater is apparently very shallow). The case study reviewed indicated that the results of the PRB treatment were pending.

Typical problems associated with the PRBs over time include (1) the Fe<sup>0</sup> medium developed problematic carbonate and sulfate mineral precipitation in the barriers (reducing porosity and contact surface area with the medium), and (2) after a certain number of PRB pore volumes pass through the gate, the efficacy of the reactive medium declines and target contaminant concentration chemical breakthrough occurs. Such problems typically developed over several years.

Although most PRBs have been emplaced within excavated trenches, high-pressure jet grouting has been used to inject reactive media slurries into the ground. For example, at Travis Air Force Base, California, a triple-rod injection system delivered a high-pressure mixture of granular iron, guar gum, air, and water to the subsurface. Injection starts at the bottom of drill holes along the base of the PRB and continues as the rod is lifted, creating a column or panel of reactive medium. Multiple rows of overlapping columns or panels create the continuous passive treatment wall. This case example apparently involved PRB injection to 50 ft below ground, but greater depths are possible (Naval Facilities Engineering Command, 2002). Jet grouting is

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discussed further in the next section of the report in addressing the vertical physical barrier process option of grout curtains.

In conclusion, the GRA of PRBs is screened out in Table 3 for Zone 3 and Zone 1 because of the requirement to emplace the reactive barriers within deep bedrock. For example, the base of Zone 3 near the leading, northern edge of the impacted water is approximately 200 ft below ground. PRBs are retained for consideration in the Southwest Alluvium (Table 3).

The GRA of revised cleanup standards is herein associated with the fact that background water quality will prohibit attainment of some remediation goals (see footnote 1 on Table 3). For present purposes, those remediation goals may be viewed as either the EPA ROD cleanup levels or the frequently more stringent comparison values flagged in Table 1. UNC recently submitted (N.A. Water Systems, 2008b) to EPA, as part of the revised SWSFS Part I, statistical calculations of background UCL95 values for all constituents (data permitting) in each of the three hydrostratigraphic units. The relevant summary tables developed with the statistical calculations are provided in Appendix B (Tables B.1 and B.2 address the Southwest Alluvium; Tables B.3 and B.4 address Zone 3; and Tables B.5 and B.6 address Zone 1). It is important to note that in Tables B.2, B.4, and B.6 the acronym CV refers to “comparison values,” and that the comparison values are identical with those flagged with green highlight in Table 1.

The GRA of ACLs derives from the conclusion, based on 20 years of site monitoring of groundwater quality trends, that certain constituents have achieved concentrations that are ALARA. For example, UNC recently submitted (N.A. Water Systems, 2008d) to NRC an ACL application for nickel in Zone 1 point-of-compliance (POC) well 604. ACLs may be appropriate for certain constituents in Zone 3 and the Southwest Alluvium. However, it is premature to formally submit any further ACL applications until the final, complete SWSFS has been submitted and reviewed by EPA and the other agency stakeholders.

The GRA of ACLs overlaps with the GRA of revised cleanup standards (in any cases where the EPA may decide to amend the current ROD cleanup levels that are tied to background water quality). Earlier determinations of background concentrations that were used as bases for ROD cleanup levels apply to sulfate, TDS, nitrate, manganese, and iron (see Table 1).

### *4.2.4 Select Representative Process Options*

To simplify the development and evaluation of alternatives, one representative process option should be selected, if possible, for each technology type remaining after the technical implementability screening procedure. Effectiveness, implementability, and cost are the criteria used to evaluate and select representative process options. The sources of information used to identify the best representative process option are the same as those used to identify technology types. During remedial design, other process options may be selected if they are found to be more advantageous (EPA, 1989b).

During screening, each alternative should be evaluated with regard to:

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- Short- and long-term effectiveness and reductions achieved in toxicity, mobility, or volume.
- Implementability including technical and administrative feasibility.
- Grossly disproportionate cost (EPA, 1989b).

The “short-term” is considered to be the remedial construction and implementation period, while “long-term” begins once the remedial action is complete and RAOs have been met. Technical feasibility includes the ability to construct, reliably operate, and meet regulations, as well as the ability to meet the operations and maintenance, replacement, and monitoring requirements after completion of the remedial action. Administrative feasibility includes the ability to obtain approvals from other agencies; the availability of treatment, storage, and disposal services; and the availability of equipment and technical expertise. The objective of the cost evaluation is to eliminate from further consideration those alternatives whose costs are grossly excessive for the effectiveness they provide. Cost estimates for alternatives should be sufficiently accurate to continue to support resulting decisions when their accuracy improves beyond the screening level. Capital, operations and maintenance, and present worth costs should be determined (EPA, 1989b).

Figure 1 shows the screening of technologies and process options. In addition to technical and administrative considerations that have been applied to produce Figure 1, qualitative cost or first-order cost estimates have also been applied to screen out select process options. This was done so that potential technologies that offer no greater benefits than other technologies, but which may be significantly more expensive, are not carried forward in the analysis.

### **4.2.4.1 Hydraulic Containment GRA**

Under the GRA of hydraulic containment with extraction and evaporation, the process options of directional wells and tunnels have been screened out at this stage. Directional wells are technically inappropriate for the Southwest Alluvium and Zone 1 hydrostratigraphic units. In the Southwest Alluvium, the relief on the underlying top of bedrock is such that complete containment in the lower part of the alluvium would be difficult, or impossible, to achieve. Additional vertical pumping wells (to supplement the existing pumping wells, which are currently shut off) could provide equivalent containment for much lower cost. As well, the Southwest Alluvium groundwater quality downgradient of Section 2 is that of either background (unsuitable for drinking given the high sulfate and TDS) or is seepage-impacted (better than background quality in generally having lower sulfate and TDS, but still unsuitable for drinking (see Chester Engineers, 2009)); thus there is no benefit from extraction pumping. Regarding tunnels for the Southwest Alluvium: they cannot be constructed in unconsolidated material.

In Zone 1, over ten years of active remedial operations, from 1989 through 1999, had reduced the saturated thickness of seepage-impacted groundwater to the point that all recovery wells were decommissioned (NRC, 1999a). The original FS calculated that a minimum pumping duration of 50 years would be needed to attain applicable or relevant and

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appropriate requirements (ARARs). Since the wells were shut off in 1999, the size of the seepage-impacted groundwater have decreased (compare Figures 48 and 49 in Chester Engineers, 2009), as have the concentrations of multiple constituents. Post-shutoff improvements in water quality are at least as great in magnitude under non-pumping conditions as when active pumping took place. Therefore, it would be inappropriate to alter this hydraulic condition, and it is doubtful that it could be improved upon because of the limited saturated thicknesses. In addition, the complex relief along the base of the central tailings cell (USFilter, 2004) would make horizontal well installation or tunneling difficult.

Directional (predominantly horizontal) wells are very expensive and, for the Zone 3 setting, at least two directional wells would be required in order to have one function as a backup. The risk of well fouling or collapse is significant. We conservatively estimate that two directional wells placed downgradient in Zone 3 would cost \$5.2 million (this estimate has been developed by applying a 30% increase to the capital cost presented for this alternative in the Zone 3 FS (MWH, 2004); see their original cost information presented as Appendix C of the present document). Various vertical well alternatives will provide equivalent performance at a much lower cost.

Tunnels (with or without drifts) have been screened out as a process option in Zone 3 for reasons including the excessive capital cost (compared with other options). We conservatively estimate that a downgradient tunnel in Zone 3 would cost \$8.3 million (this estimate has been developed by applying a 30% increase to the capital cost presented for this alternative in the Zone 3 FS (MWH, 2004); see their original cost information presented as Appendix C of the present document). Various vertical well alternatives will provide suitable performance at a significantly lower cost.

Tunnels are also screened out because of the difficulties that would be imposed by the need to manage relatively high volumes of investigation-derived wastes. The waste rock and groundwater would have to be managed as hazardous materials (according to the Contained-In-Policy). Transport of the large volumes over long distances to a suitable treatment, storage, or disposal facility would be cost-prohibitive.

### **4.2.4.2 Enhanced Extraction GRA**

The GRA of enhanced extraction in Figure 1 includes the remedial technology and process option of pumping a relatively large number of vertical wells simultaneously, in an attempt to dewater a target hydrostratigraphic unit. However, once the saturated thickness of a unit declines to a critical level pumping becomes ineffective, with the result that some volume of impacted water will not be pumpable. Note that the process option of hydraulic fracturing, toward enhanced extraction in one or more wells, has not been included in Figure 1. This is because the hydrofracture program in Zone 3 was ineffective (MACTEC, 2006); there is very little land within the UNC property in Zone 1 that could be targeted with such a program; and controlled hydrofracturing is neither needed nor relevant to the unconsolidated Southwest Alluvium.



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### **4.2.4.3 Physical Barriers GRA**

Figure 1 indicates that vertical physical barriers have been screened-out at this stage for Zone 3 and Zone 1. Note that the original EPA FS (1988b; their Figure 5-3) screened-out vertical physical barriers for all three hydrostratigraphic units for the following reason: "Aquifer too deep to implement vertical barriers." UNC also concludes that the placement of vertical barriers is screened-out for Zone 3 and Zone 1 because of the relevant depths of these bedrock units. However, EPA has requested that UNC retain the combined process options of physical barriers with extraction pumping in the Southwest Alluvium (see EPA Specific Comment 3a earlier in this report). Therefore, for current screening purposes we are presently retaining the vertical-barrier remedial technology for the Southwest Alluvium (Figure 1).

Vertical engineered barriers at contaminated sites have usually been used to achieve containment of the contamination source. Barrier walls acting as funnels to PRB gates comprise another category of application. A vertical barrier in the Southwest Alluvium would be applied as a subsurface "dam" for impacted groundwater, and thus it would be used to contain the flowing groundwater; this is an unusual application in that it would prevent the ongoing, natural draining of the SWA. Instead, the ponded water would represent a new hydraulic stress that would tend to result in a combination of infiltration into the underlying bedrock units over long timeframes, and escape of the ponded water along the barrier top or flanks (discussed below).

Regardless of the process options, any emplacement of vertical barriers would have to be preceded by a geotechnical test boring campaign to delineate the configuration of the top of bedrock underlying the alluvium sediments. This is because the barrier would, in effect, be a subsurface groundwater dam. Ideally, the barrier would achieve a hydraulically tight seal along the top of the bedrock beneath the barrier and along its flanks. Subsurface barrier flank control is very important because any "ponding" behind the barrier will tend to cause the impacted groundwater to route further downgradient by flowing along the flanks of the barrier, unless this process is controlled by the engineering. However, it would not be possible to directly confirm the absence of leakage through, or along the margins of, the engineered barrier after its construction. This is a major flaw with this intended application of vertical barriers.

Of the eight process options under the remedial technology of vertical physical barriers (Figure 1), slurry walls have been used most often at contaminated sites. As discussed further below, the thickness of the Southwest Alluvium may prohibit the proper installation of any type of vertical engineered barrier.

Of the process options for this technology shown in Figure 1, the considerations in the following paragraphs are relevant (EPA, 1998a; 1998b).

Any type of slurry wall in the Southwest Alluvium requires, in this setting, excavation of a trench down to bedrock. Maintaining an open trench of sufficient depth could not be safely

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done without the installation of trench walls plus the use of slurries. Modified excavators can remove materials to a maximum depth of approximately 80 ft – greater depths, as relevant to the Southwest Alluvium, would require the use of a crane with a clamshell, which has been used to depths of 120 ft (Naval Facilities Engineering Command, 2002).

The volume of the sediment wastes requiring disposal can be significantly decreased by employing the soil-bentonite barrier, in which the trench backfill is formed by mixing the sediments with 1% to 5% bentonite-montmorillonite clay that swells when hydrated. For this reason, the soil-bentonite slurry wall process option is retained for the Southwest Alluvium.

Although a cement-bentonite slurry wall would have greater strength than a soil-bentonite slurry wall, the former process option is screened out because of the high volume of excavated waste sediments that would have to be disposed.

A vibrating beam barrier is a type of grouted barrier that is suitable only for shallow soils; thus this process option is screened out.

Sheet piling is installed by driving interlocking sheets of steel (or sometimes plastic) down into the unconsolidated ground materials. Sheet piling can be driven to depths of 100 ft or more and they can be driven through weathered bedrock to the top of the fresh rock. The interlocking joints can present a leakage problem. The local relief on the top of rock beneath the alluvium is high (discussed more below), and it could be very difficult to achieve a laterally continuous tight seal along the boundary between the bottom of the sheet piling and the underlying bedrock. A geotechnical boring program along a proposed location of a sheet piling barrier would be necessary in order to map the top of bedrock. Sheet piling is retained as a process option.

Ground freezing consists of installing a system of freezing pipes evenly spaced in the ground along the perimeter of the volume to be isolated (Sayles and Iskandar, 1995). This process option inherently requires that the contained soils be saturated. The saturated thicknesses measured in the Southwest Alluvium monitoring wells during October 2008 (see Table 3 in Chester Engineers, 2009) had a range from 10% to 65% with a mean value of 37%. This means that the upper 60% to 70% of the alluvium could not be frozen, and that the entire array of freezing pipes would have to be installed at minimum average depths of 50 to 60 ft below ground. High energy inputs would be required in perpetuity. For these reasons, this process option is screened out.

Construction of grouted barriers involves injection of a grout into the subsurface. Pressure grouting and jet grouting are both forms of injection grouting, in which a grout mixture is injected into the pore spaces of the soil or rock. Particulate or chemical grouts may be used for grouted barriers. Particulate grouts include slurries of bentonite, cement, or both, and water. Chemical grouts generally contain a chemical base, a catalyst, and water or another solvent. Particulate grouts have higher viscosities than chemical grouts and are therefore better suited for larger pore spaces, whereas chemical grouts are better suited for smaller pore spaces. Combinations of particulate and chemical grouts can also be used (EPA, 1998a).

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The design of a permeation (pressure) grouted barrier must consider soil permeability, grout viscosity, and soil and grout particle size. In general, soils with permeabilities greater than  $10^{-3}$  cm/sec can be permeation grouted with chemical grouts, while particulate grouts can be used when soil permeabilities are greater than  $10^{-1}$  cm/sec (EPA, 1998a). Well logs in the Southwest Alluvium show that the particle sizes vary from clay to silt to sand to pebbles to occasional cobbles. The packing of these different particle sizes will have different permeabilities. Evaluation of pumping tests indicated that the average permeability of the Southwest Alluvium is  $10^{-2}$  cm/sec (Canonie Environmental, 1987), suggesting that chemical grouts may be suitable. An important advantage of grouting in some settings is the ability to install a wall around obstructions such as boulders, or a wall that conforms to a lower bounding surface that is non-planar, such as the top of bedrock underlying the Southwest Alluvium sediments. Grout barriers can also be continued into the upper part of the underlying bedrock, potentially achieving a good seal along the base of the alluvium.

The design of a permeation grouted barrier must include a thorough evaluation of the pressure to be used. Excessive pressure can cause hydrofracturing; if this occurs, the grout will be forced into the hydrofractures but may not adequately fill the natural soil voids, and therefore the barrier would not meet the permeability design requirement.

Jet grouting is an established practice to improve the structural characteristics of soil for construction purposes. More recently, it has been used to inject grouts to make impermeable walls (EPA, 2007).

Like permeation grouting, jet grouting requires that injection pressure and volume be monitored closely. If spoil materials cannot be expelled to the surface, excess pressure can build and cause hydrofracturing. Jet grouting can produce large amounts of spoil materials; if these materials are contaminated, then they require appropriate waste handling and disposal.

The design of a jet grouted barrier involves injecting grout at very high pressure (up to 6,000 psi) into the soil. The high-pressure grout is injected at very high rates which cuts and mixes the native soil into a uniform barrier (with finer sized spoil returned to the surface). Typically a Portland cement grout is used, although a variety of grouts can be used. A horizontally continuous barrier can be created by successive installation of jet-grouted columns or panels. Jet grouting can be used to stabilize soils ranging from gravels to heavy clays. Jet grouted barriers have been built to depths of greater than 200 ft, although below 100 ft the verticality and thus the continuity of jet grouted barriers are difficult to confirm or control (EPA, 1998a).

Grout curtains are retained as a vertical-barrier process option for the Southwest Alluvium. However, given the thickness of the alluvium sediments there is a risk that the barrier would not be ideally continuous and that some impacted groundwater would not be contained.

Deep soil mixing technology consists of in-situ mixing of soil and a slurry. The specially designed equipment typically consists of three auger mixing shafts that inject and mix a

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water-bentonite or cement-bentonite slurry into the soil as the augers are advanced, resulting in a column of thoroughly mixed soil. The final mix is about 1% bentonite. A continuous barrier is formed by overlapping penetrations. The bottom of a deep soil-mixed barrier cannot be inspected to confirm penetration into the underlying bedrock, which could allow leakage of groundwater. Because contaminated materials are not excavated, the advantages of using deep soil mixing include reduction of health and safety risks and elimination of costs associated with handling and disposal of contaminated waste sediments. Deep soil mixing is retained as a process option.

A continuous vertical engineered barrier across the width of the local saturated alluvium should be combined with upgradient extraction pumping, toward the objective of hydraulic containment plus extraction and evaporation. One potential advantage for this combination of process options is that the vertical barrier would locally facilitate maintaining saturated thicknesses suitable for pumping relatively larger volumes of impacted groundwater.

However, the installation of vertical physical barriers in the Southwest Alluvium confronts two physical obstacles that are very likely insurmountable: (1) the thickness (and thickness variations) of the alluvium sediments, and (2) the dynamic nature of the alluvium sediments.

The thickness of the Southwest Alluvium presents a formidable technical impediment to the emplacement of a continuous grout barrier through the entirety of the alluvium (preferably to be keyed or socketed into the upper part of the underlying bedrock). The alluvium thickness along the present monitoring well array (see Table 3 in Chester Engineers, 2009) averages 88 ft and defines a range from 57 ft (well GW-3) to 132 ft (well 807). This range defines locally steep relief along the top of the bedrock. In the vicinity of wells GW-1, GW-2, and GW-3, such a grout barrier would have to vary (just to reach the top of bedrock) from 57 to 90 ft deep – its length would have to cover a minimum of ~750 ft (approximately spanning the impacted groundwater in Appendix Figure A.1) to a maximum of ~1000 ft (approximately spanning the width of the entire saturated alluvium). These difficult sediment conditions also pertain to considerations of installing a funnel-and-gate permeable reactive barrier (discussed more below).

The alluvium sediments along Pipeline Arroyo and Pipeline Canyon are unstable and dynamic. Although little to no surface water flows along these features during drier times of the hydrologic year, occasionally large rainfalls and heavy snowmelt events cause very strong surface flows that transport large volumes of the sediments further downgradient. This means that no ground structures of any sort can be placed within the flow channels because the heavy flows will destroy them. Filled trenches and vertical barriers are likely to be damaged and destroyed by the occasional heavy flooding and sediment transport. The erosive power of channelized surface flow is demonstrated by the presence of Pipeline Canyon, which is incised downgradient of the Nickpoint (upgradient of which is Pipeline Arroyo), and the erosional sculpting of the bedrock exposed at the Nickpoint. (The Nickpoint is located in Appendix A Figure A.1.)

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UNC concludes that the installation of reactive barriers or vertical physical barriers is likely not technically implementable for the Southwest Alluvium. Even if a continuous and hydraulically tight physical barrier could be installed, the physical integrity of the barrier would be seriously threatened by occasional large floods. However, because of EPA's stated preference for including these GRAs through this level of screening (see above EPA General Comment 6 and Specific Comment 3.b), they are retained for consideration in the Southwest Alluvium in Figure 1. If the option of PRBs is pursued, then specific target constituents must be selected. Multiple reactive-medium gates may be required to optimally address the target constituents. A bench-scale treatability study would be appropriate.

Next we consider the process option of hydraulic barriers (or hydraulic "fences") created by an array of vertical injection wells (under the GRA of physical barriers). Any such injection water would have to be of relatively high quality, for which the most practicable source may be from deep wells into either the Dakota Formation or the Westwater Canyon Formation. This option is a type of hydraulic containment of impacted groundwater. Each hydrostratigraphic unit poses its own technical issues. In Zone 1, such a hydraulic barrier would have to derive from injection wells located within the narrow strip of land between the eastern edge of the Central Cell and the western boundary to Section 1 (approximately 125 ft measured along an east-west direction; see Appendix A Figure A.3). The direction of groundwater flow and constituent transport in Zone 1 is toward the north-northeast. Injection-well flooding is inadvisable because it will cause groundwater mounding in the area surrounding the injection wells. This would increase the local hydraulic gradients and the groundwater flow rates. In turn, this would reduce the present efficacy of natural attenuation by reducing the groundwater contact time with the Zone 1 bedrock. The long-term reductions in groundwater levels, in the updip area of Zone 1, have promoted effective natural attenuation by neutralization, adsorption, and degradation. For these reasons, hydraulic barriers are screened out for Zone 1 in Figure 1.

In the Southwest Alluvium, hydraulic barriers may be a needlessly aggressive option because the alluvium matrix materials are especially effective at geochemically buffering the seepage impact. This is shown by the near-neutral pH of most of the impacted groundwater in this hydrostratigraphic unit. If any hydraulic barrier were designed to address the entire width of the saturated alluvium, then long-term functionality would require upgradient extraction well pumping in order to avoid "spillover" of the barrier. It should be noted that any water introduced to the alluvium will tend to undergo geochemical interactions with the sediment matrix that will cause elevation of the concentrations of sulfate and TDS to levels above the current ROD cleanup levels and the comparison values as defined in the present report. This is because the introduced water will tend to reach equilibrium with the alluvium mineral gypsum (or other chemically similar minerals composed largely of calcium and sulfate).

Along the advancing northern front of seepage impact in Zone 3, close to the northern property boundary of Section 36, a hydraulic barrier could provide effective hydraulic containment. However, unless this option would be combined with upgradient extraction

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well pumping, there will be a tendency for impacted water to try to migrate around the westernmost injection well in the array. It should be noted that the eastern boundary of the area of Zone 3 seepage impact is defined by the complete loss of saturated thickness (see Appendix A Figure A.2 and note the zero-saturation boundary line). The injection of water in the northern part of Zone 3 would potentially change the location of this hydraulic boundary.

### **4.2.4.4 Hydraulic Flushing GRA**

Next we consider the GRA of hydraulic flushing with extraction and evaporation. Flushing involves the controlled injection and extraction of water. The process option of alkalinity amendments to injection waters is intended to lower the pH in areas of relatively highly impacted groundwater, while displacing and extracting the impacted water. The alternative process option involves injection of high quality water, without alkalinity amendments, in order to dilute, displace, and extract impacted water. Such high quality water might be obtained by installing deep wells into either the Dakota Formation or the underlying Westwater Canyon Formation (the site's Mill Well taps the later source).

In Zone 1, the low hydraulic conductivity of the bedrock is a significant impediment; this factor may prohibit the effective application of flushing. The following issues are also important to consider: (1) the requirement to keep all injection and extraction wellheads on UNC property; (2) the narrowness of the strip of land between the eastern edge of the Central Cell and the Section 1 boundary; and (3) the groundwater flow direction is toward the north-northeast. Based on these spatial and technical considerations, UNC concludes that flushing of Zone 1 impacted water is not a feasible remedial option. This conclusion is consistent with the results of the recent pilot-study attempt to create a flushing system in Zone 3. This attempt to inject alkalinity-charged water into the sandstone was terminated because the attainable injection rates were far lower than anticipated (ARCADIS BBL, 2007). For these reasons, we have screened out these two process options in Figure 1 for Zone 3 and Zone 1.

The impacted water in the Southwest Alluvium has relatively elevated concentrations of bicarbonate (i.e., alkalinity) in comparison to the background water quality (see Appendix A Figure A.1 with posted concentrations of both bicarbonate and sulfate in the Southwest Alluvium wells in October 2008). Therefore, flushing with alkalinity-amended water is not applicable. Flushing of the impacted water with relatively high-quality water from deep wells is retained as potentially applicable for the Southwest Alluvium in Figure 1 (see above [EPA Specific Comment 3.c](#)). However, it is noted that none of the impacted water within the Southwest Alluvium, and outside of the UNC property, shows exceedances of current site standards for hazardous constituents. This is because such constituents are attenuated naturally within Section 2 (see the discussion of these issues, and related issues of background water quality, in the most recent annual report by Chester Engineers, 2009). The implementability of such a flushing system in the Southwest Alluvium would be complicated by the fact that impacted alluvium groundwater extends upgradient, to the northeast, for over 5,000 ft from the southwestern boundary of Section 2 along the western margin of all three

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tailings cells (see Appendix A Figure A.1). Flushing that was spatially restricted to the water near the southwestern boundary of Section 2 would not change the fact that upgradient impacted water would continuously flow into the flushing zone over very long time frames. Alternatively, flushing that was spatially associated with injection of water farther upgradient, along the western edge of the North Cell, would require that the injected water take 100 years or more to flow downgradient to the southwestern boundary of Section 2.

### **4.2.4.5 Treatment GRA**

The GRA of treatment and the two related process options have been screened out because of the technical and cost issues shown in the right-most column of Figure 1. Treatment of impacted water by reverse osmosis (RO) offers no benefit over evaporation, which has been successfully used and is already in place at the site. Also, RO produces considerable byproduct sludge that requires offsite transport and disposal.

### **4.2.4.6 ICs GRA**

ICs have been provisionally retained as potentially useful for Sections 1, 3, and 10, which are Indian Trust Lands. However, the application of IC measures would require certain action on the part of the Navajo Nation and/or the Bureau of Indian Affairs. As early as 2000, UNC engaged the Navajo to discuss ICs. In the ensuing nine years, there has been no movement toward the adoption of the basic IC framework that includes an environmental right-of-way and a Tribal Resolution. See the letters from Davis, Graham & Stubbs to various Navajo technical and legal representatives (dated February 29, 2000; March 5, 2001; and March 23, 2001). ICs are retained for potential application to Section 2 and 36.

### **4.2.5 Summary of Remedial Alternatives for Each Hydrostratigraphic Unit & Further Screening**

UNC understands EPA's request for the revised SWSFS Part II to present a single groundwater remedy for the operable unit (see above EPA General Comment 3 Paragraph [2]). However, given the complex site hydrogeology, it is appropriate to review the remedial alternatives that have so far been developed for each hydrostratigraphic unit. Such summaries in Tables 4, 5, and 6 are discussed next. The comments in the right-most columns of these tables summarize key relevant issues for the alternatives. The comments below are supplemental to these three tables.

#### **4.2.5.1 The Southwest Alluvium**

There are 9 alternatives for the Southwest Alluvium in Table 4. Alternative 5, vertical physical barriers, will ultimately fail in this thick alluvium setting that is accompanied by dynamic erosional and depositional characteristics brought on by periodic flooding of Pipeline Arroyo. Regardless of the process options, there are concerns about the barrier's physical continuity along its base and flanks (especially at potential depths greater than 100 ft below ground), and its physical stability in the dynamic setting that involves occasional large floods.

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Since a vertical barrier would need to be combined with upgradient extraction well pumping, to control possible ponded groundwater spillover or routing around the sides of the barrier, UNC concludes that a new extraction well array, absent the vertical barrier, is a much more cost-effective option. Such an array might include the former pumping wells plus new pumping wells, with the objective being hydraulic containment of the impacted groundwater – this is Alternative 9 in Table 4. Numeric or analytic groundwater modeling can be used to design an optimal extraction well configuration and to predict possible pumping rates required for containment. For all of the above reasons Alternative 5, vertical physical barrier, is screened out.

For Alternative 6, hydraulic barrier from injection wells, numerical or analytic groundwater modeling is advised to evaluate the efficacy of specific, alternate injection well arrays or configurations. Such modeling should include extraction wells, which are a necessary component of this alternative. Such extraction pumping does not have to provide full capture or hydraulic containment of all the seepage-impacted water, but it should compensate for the injected water such that the system maintains critical induced hydraulic gradients formed by injection. The source for such injection water has not been established. Although Alternative 6 is likely to be technically feasible, its implementation would serve no constructive purpose. The result would be mixing of the injected and seepage-impacted waters that would produce water that still exceeds the standards. This would not constitute a “barrier” to anything. For these reasons Alternative 6, hydraulic barrier from injection wells, is screened out.

Alternative 7, permeable reactive barriers, notes that the target contaminants will drive the choice of reactive media. For example, if sulfate was ranked as a high priority constituent, then a reactive medium of organic carbon might be prioritized. However, it is important to note that after sulfate effluent concentrations are reduced, the treated groundwater will continue to flow downgradient, and because of the geochemical mechanisms tied to gypsum equilibrium, the treated water will evolve toward concentrations of sulfate (and TDS, of which sulfate is the major component) that will exceed the current ROD cleanup levels and the comparison values. The background water in the Southwest Alluvium frequently exceeds the ROD cleanup levels. Passive treatment of sulfate by groundwater flow through a PRB (or any other type of treatment) therefore would not be effective. Regardless, it is noted that use of zero-valent iron as a reactive medium not only promotes reduced concentrations of many metals and uranium, it also causes the precipitation of sulfide minerals onto the PRB medium, which reduces the effluent concentrations of sulfate. However, it will also tend to increase the alkalinity of the effluent water -- given that the concentrations of alkalinity and uranium are generally covariant in the Southwest Alluvium, this is a potentially undesirable outcome. Sulfide mineralization will tend to foul the PRB medium relatively quickly due to high sulfate loading (discussed below).

Carefully monitored case studies indicate that PRB reactive media will tend to lose efficacy on the scale of several years. This reflects precipitation and loss of porosity of the medium;



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adsorption of contaminants onto the grains in the medium; and the inherent loss of reactivity capacity of the medium. Restoration of the reactivity and porosity of the reactive medium is not possible in a setting such as the Southwest Alluvium. The only feasible correction to this problem would be the successive installation of new PRBs with fresh media. The funnel walls could be designed with this in mind, but the relevant restoration time frames are daunting in this setting, considering the following. The Southwest Alluvium impacted groundwater extends upgradient, toward the northeast, for approximately one mile from the southwestern boundary of Section 2 (it is noted that the hydraulic continuity along this entire distance has not been demonstrated but it is herein assumed). From the northwestern corner of the North Cell, impacted alluvium water would require the following estimated timeframes for flow downgradient to the southwestern property boundary in Section 2 (for present purposes, the rate of groundwater flow is equated with the rate of constituent transport): to flow one mile at a rate of 52 ft/yr would require 102 years. If the average flow rate were assumed to be 30 ft/yr (which is plausible) then the time required increases to 176 years. Assuming that PRB gates would need to be replaced every five years, then over 102 years 20 gates would be required, and over 176 years 35 gates would be required.

PRBs including funnel walls have some of the same problematic issues as vertical barriers. Even after a preliminary geotechnical boring program to try to map the configuration of the top of bedrock along the base and sides of the funnel walls, it would not be possible to obtain direct confirmation that the funnels had hydraulically tight seals and were not leaking. Surface to near-surface parts of the funnels and gates would occasionally be subjected to damaging large floods. For all of the above reasons Alternative 7, permeable reactive barriers, is screened out.

Alternative 8, hydraulic flushing, has drawbacks regarding conceptual design. Although the location of injection wells for the flushing water could be located, in principle, anywhere upgradient of the southwestern Section 2 property boundary, it is important to understand that the design needs to address impacted water that is located relatively far upgradient that would otherwise serve as a long-term source of continued downgradient transport of contaminants.

We note that the hydraulic continuity of impacted water, extending over one mile along the western flanks of the tailings cells, has not been directly demonstrated; it is a historic artifact in the graphic depiction of the extent of the impacted water (though it may be correct). Our evaluation of the October 2008 saturated thickness in the Southwest Alluvium suggests the possibility that groundwater just upgradient of the Nickpoint may be locally ponded and lacking contiguity with the groundwater just east of and downgradient of the Nickpoint (note the narrowing of the depicted saturated alluvium in this location in Appendix A Figure A.1). However, this possibility cannot be confirmed with a high degree of confidence with the available groundwater elevation data. For purposes of present analysis, hydraulic continuity is assumed, consistent with the depiction of the impacted water shown in Appendix A Figure A.1.

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Injection wells for flushing water could be located relatively far upgradient within the Southwest Alluvium plume. However, the time required for downgradient flow of the flushing water to reach, for example, an extraction well system located within UNC property near the GW-series wells, may be very prohibitive. For example, assuming an average groundwater flow rate of 52 ft/yr over the length of the Southwest Alluvium impacted water, it would require 102 years for the leading edge of the flushing water to reach the extraction wells. Doubling the average flow rate (an unrealistic alternative) would only halve the flow traverse time to approximately 50 years. As this water flowed through the alluvium it would acquire the sulfate and TDS concentrations characteristic of all waters in contact with the alluvium matrix minerals (especially gypsum), which would exceed the current ROD cleanup levels and comparison values for these constituents.

Injection water for flushing could be located farther downgradient; for example, along a linear array through well 803, oriented normal to the groundwater flow direction. This would allow a maximum flushing circuit length of approximately 800 ft to the downgradient locations of a hypothetical extraction well array located close to the Section 2 boundary. At an average groundwater flow rate of 52 ft/yr, the first particles of injected flushing water would require approximately 15 years to reach the Section 2 boundary. However, in this scenario, impacted groundwater located to the northeast of the injection wells will tend to constantly flow to the southwest, into the flushing circuit. As discussed earlier, given the length of the Southwestern Alluvium plume, such continuous input of impacted water could occur for more than 100 years.

Restricting the locations of the injection and extraction wells to UNC property means that any such flushing system would not address offsite impacted water in Sections 3 and 10 (though this water has quality that is somewhat better than background water). The existing alluvium groundwater has been interacting with the matrix minerals for approximately 40 years, and that the highest concentrations of sulfate and TDS in any of the Southwest Alluvium wells is in background well SBL-1 (see the discussion in Chester Engineers, 2009; and note the sulfate concentration posted next to this well in Appendix A Figure A.1).

In any relevant flushing scenarios, long-term pumping of an extraction well array will be required near the Section 2 boundary. As a result, the benefits of containment using extraction wells removes any possible benefit of flushing. NRC (1996; p. 16) reached the same conclusion, stating the following about the remedial option of flushing: "Adding fresh water to the system has been considered as a possible remediation strategy ... Although fresh water injection may help dilute the salts in the system, the staff is concerned that there will be no time at which this proposed activity could cease."

In summary, there is no benefit to adding water to the alluvium system that is draining on its own. Added water would just have to be extracted and treated. For all of the above reasons Alternative 8, hydraulic flushing, is screened out.

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Alternative 9, hydraulic containment using vertical extraction wells, raises the issue of calculating the groundwater flux through the Southwest Alluvium. This has been done by developing a map of the unit's saturated thickness during October 2008, and estimating the average wetted cross sections (oriented normal to groundwater flow toward the southwest) at the three following well locations: 805 (wetted section length 694 ft); GW-2 (968 ft); and 624 (1792 ft). These three cross sections have been averaged because the different locations provide flux values that vary by a factor of approximately two. Of course, the flux should be relatively constant through the area and the variance probably derives from the following two factors: (1) uncertainty about the actual wetted cross-sectional areas; and (2) the inability to resolve, from monitoring well measurements, the local-scale differences of seepage velocity that undoubtedly occur.

The flux estimates incorporate the following hydraulic parameters: a groundwater velocity of 52 ft/yr (the average Darcy seepage velocity recently calculated between wells 805 and 624; see Chester Engineers, 2009, Table 5); and an effective porosity of 31% (Chester Engineers, 2009, Table 5 footnote on information sources). The results of the calculations of groundwater flux are as follows:

- Average impacted cross-sectional area = 14,620 ft<sup>2</sup>
- Impacted groundwater flux = 235,674 ft<sup>3</sup>/yr (26.9 ft<sup>3</sup>/hr or 3.35 gpm)
- Average total cross-sectional area = 21,349 ft<sup>2</sup>
- Total groundwater flux = 344,150 ft<sup>3</sup>/yr (39.3 ft<sup>3</sup>/hr or 4.90 gpm)

Uranium may present a special issue in consideration of extraction well pumping in the Southwest Alluvium. EPA has informally stated that they are considering amending the ROD to apply the current uranium MCL. Footnote 1 in Table 4 (and also present in many of the other tables and figures) notes that this condition would be problematic for achieving compliance in the Southwest Alluvium. For example, as discussed in the 2008 site annual review report (Chester Engineers, 2009), over the long-term and through 2008 uranium concentrations in the Southwest Alluvium have not exceeded either of the current site standards of 5 mg/L (ROD cleanup level) or 0.3 mg/L (NRC License groundwater protection standard). The potential ARAR for uranium of 0.03 mg/L comprises both the EPA MCL and the NMWQCC health-based standard (see Table 1 for all of these values). Time-series charts (Chester Engineers, 2009) show that if the site uranium cleanup level is lowered to 0.03 mg/L, then almost all of the background water, in addition to the impacted water, in the Southwest Alluvium would not be in compliance.

Considering the screening that has been accomplished to this point, lowering of the site cleanup level to 0.03 mg/L would leave the remedial option for uranium cleanup in the Southwest Alluvium as dewatering of all alluvial water. If this were attempted the pumping yields will decline sharply because the pumping will reduce the saturated thickness to the point where pumping is no longer feasible. This issue was put forth in Appendix A of the ROD and is no less true now than it was then.

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Complicating the issue of remediating uranium concentrations to any level below 0.3 mg/L in the Southwest Alluvium is the commonly covariant relationship of uranium and bicarbonate concentrations. Background waters contained higher uranium concentrations than those derived from tailings impact, and the alluvium matrix may contain significant adsorbed uranium that can remobilize into the groundwater (GE, 2006).

### **4.2.5.2 Zone 1**

Zone 1 alternatives are summarized in Table 5. For Alternative 1, no further action, it is important to note that the former pumping locations in Zone 1 met the decommissioning criteria, and that pumping accomplished no improvement in water quality. Attenuation processes are occurring and the groundwater is being monitored. All hazardous substances that may migrate offsite from Zone 1 are in compliance with groundwater cleanup objectives; this has been analyzed in the Zone 1 ACL application (N.A. Water Systems, 2008d).

In October 2008, there were no exceedances of hazardous constituents outside of Section 2 (see Table 16 in Chester Engineers, 2009). This is the case for both current ROD cleanup levels and comparison values. The only Section 1 exceedances are for sulfate and TDS (impacted wells EPA-5 and EPA-7, and background well EPA-4) and manganese (background well EPA-4). The seepage-impacted area is decreasing and is defined solely by the indicator parameters chloride (mapping criterion of 50 mg/L or more, versus the current ROD cleanup level and comparison values of 250 mg/L) and pH. The area of impacted water is decreasing (Chester Engineers, 2009). The offsite groundwater quality has been gradually improving since the last extraction wells were shutoff during 1999.

For reasons discussed earlier in this report, and those provided as comments in Table 5, Alternative 5, hydraulic containment with evaporation and extraction, and Alternative 6, enhanced extraction, are screened out.

### **4.2.5.3 Zone 3**

Zone 3 alternatives are summarized in Table 6. All of the alternatives shown have been discussed earlier and they are retained for further consideration. Alternative 2, ICs for Section 36 if needed, has not been formally proposed. This is because the status of Section 36 is presently unclear in the context of whether it will be included, with Section 2, in the eventual transfer of the UNC property to the DOE for long-term stewardship. This issue was left open in the ROD. In Appendix H (Responsiveness Summary [not paginated]) of the ROD, the Response to Comment 6 it states: "The exact area to be decided to the Department of Energy has not been determined." It is unknown whether or not this will include Section 36.

### **4.2.6 Select Representative Process Options**

To simplify the development and evaluation of alternatives, one representative process option should be selected, if possible, for each technology type remaining after the technical implementability screening procedure. Effectiveness, implementability, and cost are the criteria

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used to evaluate and select representative process options. The sources of information used to identify the best representative process option are the same as those used to identify technology types. During remedial design, other process options may be selected if they are found to be more advantageous (EPA, 1989b).

This step in the FS process will later be followed by the assembly of technologies into alternatives (which will be presented as a matrix comprising the site as a single operable unit with a single groundwater remedy).

Figure 2 presents the selection of representative process options. Cost screening comments in the right-most column follow the guidance of EPA (1989b; p. 3) and EPA (1988d; Figure 4-5). One process option is shown for each technology type with the following exceptions: (1) for the GRAs of no further action, revised cleanup standards, and alternate concentration limits, the process options are, respectively, not applicable, none, and none; and (2) for the GRA of ICs, two process options are shown in order to address both access and use restrictions, and offsite groundwater monitoring.

### *4.2.7 Summary of Response Actions, Technologies & Representative Process Options Selected for Further Development*

Figure 3 is presented as an interim step toward developing combined remedial alternatives (discussed in the next section). Inclusion of this step follows the example of the original 1988 EPA site FS (their Figure 5-5). The shading in the right-most column indicates the selected potential for combined remedial alternatives (i.e., individual technologies and representative process options that may be combined, in varied groupings).

Note that the response action of ICs occupies two rows. The second row is shown to represent the potential for ICs to be an individual remedial alternative (no shading in the right-most cell); and the bottom row is shown to represent the potential for ICs to be part of one or more combined remedial alternatives (right-most cell is shaded).

### *4.2.8 Assemble Technologies into Remedial Alternatives*

To assemble alternatives, general response actions should be combined, using different process options applicable to different volumes of media or areas of the site, to meet all remedial action objectives. Consideration should also be given to how general response actions may be best handled together. A description of each alternative should be included in the FS report, including the logic behind the assembly of the specific remedial action alternatives (EPA, 1989b).

As appropriate for this site, and following the original 1988 EPA FS, combined remedial alternatives have been developed from the hydrostratigraphic-unit-specific alternatives that have passed through the previous steps of screening.

Figure 4 comprises a matrix defined by four combined remedial alternatives in the left column (defining rows in the matrix) and the individual components of the combined remedial

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alternatives shown along the various column headers. Six component response actions are broken out for each of the three hydrostratigraphic units. The right-most column indicates that evaporation (part of the current site remedy for Zone 3) is integral to all four of the combined remedial alternatives.

For the Southwest Alluvium and Zone 3, the following groundwater alternatives have been carried forward from the initial screening: containment and extraction (combined remedial alternative No. 1 on Figure 4). For the Southwest Alluvium and Zone 1, the individual alternatives of no further action and ICs survived initial screening. The no further action alternative did not pass initial screening for Zone 3 because the groundwater impacts have not stabilized. The individual alternative of ICs has been applied to Zone 3, although their potential future role in Section 36 is unclear (i.e., turn over of Section 36 to DOE for long-term care).

For the Southwest Alluvium and Zone 3, the following alternatives survived initial screening: (a) containment and extraction (with potential offsite ICs in the Southwest Alluvium and Zone 1 these define combined remedial alternative No. 2 on Figure 4); (b) enhanced extraction (with potential offsite ICs in the Southwest Alluvium and Zone 1 these define combined remedial alternative No. 3 on Figure 4); and (c) hydraulic barriers and extraction (with potential offsite ICs in the Southwest Alluvium and Zone 1 these define combined remedial alternative No. 4 on Figure 4).

As shown in the right-most column of Figure 4, all four of the combined remedial alternatives employ evaporation of extracted groundwater. During the 20 years of active corrective action on the site, including various pumping well arrays in the three hydrostratigraphic units, the extracted water has been effectively managed by evaporation in the two ponds overlying the South Cell.

The combined remedial alternatives may be implemented in ways that deviate from their assembled components in Figure 4. For example, combined remedial alternative No. 3 includes enhanced extraction onsite for the Southwest Alluvium and Zone 3 (this response action did not pass initial screening for Zone 1). This does not mean that enhanced extraction, if chosen for implementation, would necessarily proceed in both hydrostratigraphic units. One should keep in mind that the individual response actions and combined remedial alternatives shown in Figure 4 are those that are feasible based on screening of effectiveness, implementability, and cost.

Enhanced extraction in Zone 3 was included in the Zone 3 Supplemental FS (MWH, 2004). Appendix C shows that two alternate Zone 3 enhanced well fields were considered: one comprising 70 wells, and the other comprising 140 wells. If such a large amount of pumpage occurred in Zone 3, especially in conjunction with enhanced extraction in the Southwest Alluvium, the volume of the groundwater discharges could overwhelm the capacity of the two evaporation ponds overlying the South Cell. In such a scenario, some of the extracted water would have to be discharged into Pipeline Canyon at a location downgradient of any extraction wells in the Southwest Alluvium.

## Section 5

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# Tables

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**TABLE 1**  
 Contaminant-Specific Groundwater Cleanup Levels and Other Comparison Values  
 United Nuclear Corporation, Church Rock Site  
 Church Rock, New Mexico

| Source                 | Standards Used for 2nd 5-Year Review<br>(September 2003, Table 3-1) and ROD (September 1988) |              |   |                     | NRC Source<br>Materials | Potential ARARs                    |                          |                                 |                    | Standard Compared to in 2007<br>Annual Review |          | Current Health-Based Criteria (+) |                           |        |
|------------------------|--|--------------|---|---------------------|-------------------------|------------------------------------|--------------------------|---------------------------------|--------------------|---|----------|-----------------------------------|---------------------------|--------|
|                        | New Mexico WQCC<br>Standards   | Health-based | Maximum<br>Concentration Limit<br>(MCL) | Background<br>Level |                         | License<br>Compliance<br>Standards | NRC<br>Appendix<br>List* | New Mexico<br>WQCC<br>Standards | EPA Drinking Water |   | EPA      | NRC                               | Health-Based<br>Criterion | Source |
|                        |  |              |   |                     |                         |                                    |                          |                                 | MCL                | Other**                                       |          |                                   |                           |        |
| Sulfate                |  |              |   | 2160                |                         |                                    | 2125***                  |                                 |                    | 2125***                                       |          |                                   |                           |        |
| Total Dissolved Solids |  |              |   | 3170                |                         |                                    | 4800***                  |                                 |                    | 4800***                                       |          |                                   |                           |        |
| NO3 as N               |  |              |   | 30                  |                         |                                    | 190***                   | 10                              |                    | 190***  |          | 10                                | R6HHSL, MCL               |        |
| Manganese              |  |              |   | 2.6                 |                         |                                    | 0.2                      | O                               |                    | 2.6   |          | 1.7                               | R6HHSL                    |        |
| Chloride               | 250  |              |   |                     |                         |                                    | 250                      | O                               |                    | 250   |          |                                   |                           |        |
| Aluminum               | 5  |              |   |                     |                         |                                    | 5                        | I                               |                    | 5   |          | 37                                | R6HHSL                    |        |
| Antimony               |  | 0.014        |   |                     |                         |                                    |                          |                                 | 0.006              |   |          | 0.006                             | MCL                       |        |
| Arsenic                |  |              | 0.05                                    |                     | 0.05                    | 0.05                               | 0.1                      | HH                              | 0.01               | 0.05  | 0.05     | 0.01                              | MCL                       |        |
| Barium                 | 1  |              | 1                                       |                     |                         | 1                                  | 1                        | HH                              | 2                  |   |          | 2                                 | MCL                       |        |
| Beryllium              |  | 0.017        |   |                     | 0.05                    |                                    |                          |                                 | 0.004              | 0.017   | 0.05     | 0.004                             | MCL                       |        |
| Cadmium                | 0.01   |              | 0.01                                    |                     | 0.01                    | 0.01                               | 0.01                     | HH                              | 0.005              | 0.01  | 0.01     | 0.005                             | MCL                       |        |
| Chromium               | 0.05   |              | 0.05                                    |                     |                         | 0.05                               | 0.05                     | HH                              | 0.1                |   |          | 0.1                               | MCL                       |        |
| Cobalt                 | 0.05   |              |   |                     |                         |                                    | 0.05                     | I                               |                    | 0.05  |          | 0.73                              | R6HHSL                    |        |
| Copper                 | 1  |              |   |                     |                         |                                    | 1                        | O                               | 1.3                | MCLG & TT                                     |          | 1.3                               | MCL                       |        |
| Iron                   |  |              |   | 5.5                 |                         |                                    | 1                        | O                               |                    |   |          | 26                                | R6HHSL                    |        |
| Lead                   | 0.05   |              | 0.05                                    |                     | 0.05                    | 0.05                               | 0.05                     | HH                              | 0.015              | MCLG & TT                                     | 0.05     | 0.05                              | 0.015                     | MCL    |
| Mercury                | 0.002  |              | 0.002                                   |                     |                         | 0.002                              | 0.002                    | HH                              | 0.002              |   |          | 0.002                             | MCL                       |        |
| Molybdenum             | 1  |              |   |                     |                         |                                    | 1                        | I                               |                    | 1   |          | 0.18                              | R6HHSL                    |        |
| Nickel                 | 0.2  |              |   |                     | 0.05                    |                                    | 0.2                      | I                               |                    | 0.2   | 0.05     | 0.73                              | R6HHSL                    |        |
| Selenium               |  |              | 0.01                                    |                     | 0.01                    | 0.01                               | 0.05                     | HH                              | 0.05               | 0.01  | 0.01     | 0.05                              | MCL                       |        |
| Silver                 | 0.05   |              | 0.05                                    |                     |                         | 0.05                               | 0.05                     | HH                              |                    |   |          | 0.18                              | R6HHSL                    |        |
| Thallium               |  | 0.014        |   |                     |                         |                                    |                          |                                 | 0.002              | MCLG = 0.0005                                 |          | 0.002                             | MCL                       |        |
| Vanadium               |  | 0.7          |   |                     | 0.1                     |                                    |                          |                                 |                    | 0.7   | 0.1      | 0.18                              | R6HHSL                    |        |
| Zinc                   | 10   |              |   |                     |                         |                                    | 10                       | O                               |                    |   |          | 11                                | R6HHSL                    |        |
| TTHMs****              |  |              |   |                     | 0.08                    |                                    | 0.1                      | HH                              | 0.08               | MCLG = 0.07****                               |          | 0.08                              | 0.08                      | MCL    |
| Uranium                | 5  |              |   |                     | 0.3                     |                                    | 0.03                     | HH                              | 0.03               | 5   | 0.3      | 0.03                              | MCL                       |        |
| Radium 226 and 228     |  |              | 5 pCi/l                                 |                     | *****                   | 5 pCi/l                            | 30 pCi/l                 | HH                              | 5 pCi/l            | 5 pCi/l                                       | *****    | 5 pCi/l                           | MCL                       |        |
| Lead-210               |  |              | 1 pCi/l                                 |                     |                         |                                    |                          |                                 |                    |   | 1 pCi/l  | 0.0541 pCi/l                      | PRG                       |        |
| Thorium-230            |  |              | 15 pCi/l                                |                     | 5 pCi/L                 |                                    |                          |                                 |                    |   | 5 pCi/l  | 0.523 pCi/l                       | PRG                       |        |
| Gross Alpha            |  |              | 15 pCi/l                                |                     | 15 pCi/l                | 15 pCi/l                           |                          |                                 | 15 pCi/l           | 15 pCi/l                                      | 15 pCi/l | 15 pCi/l                          | MCL                       |        |

SO4  
TDS  
NO3  
Mn  
Cl2  
Al  
Sb  
As  
Ba  
Be  
Cd  
Cr  
Co  
Cu  
Fe  
Pb  
Hg  
Mo  
Ni  
Se  
Ag  
Tl  
Zn  
V  
TTHMs  
U  
comb Ra  
Pb-210  
Th-230  
GA

Notes:

Units = mg/L unless otherwise noted

Yellow cells = constituents not analyzed since site active remediation started in 1989, per EPA FS (August 1988) and ROD (September 1988)

\* 10 CFR Appendix A to Part 40

\*\* "Other" includes non-zero Maximum Contaminant Level Goals (MCLG) or Treatment Technology Action Levels (TT)

\*\*\* New Mexico Environment Department recommended background values (letter to EPA of January 6, 1998); EPA has not formally adopted these revisions

\*\*\*\* TTHMs (total trihalomethanes) include chloroform; TTHMs MCL = 0.08 mg/L; in addition, chloroform has an MCLG = 0.07 mg/L

\*\*\*\*\* Combined radium NRC Site Groundwater Protection Standards are 5.0 pCi/L for Zone 3; 5.2 pCi/L for Southwest Alluvium (background); and 9.4 pCi/L for Zone 1 (background)

(+) Sources of health-based criteria include EPA Region 6 Human Health Medium-Specific Screening Levels (R6HHSL) and EPA Preliminary Remediation Goals for Radionuclides (PRGs). For those contaminants with federal MCLs, the MCL is shown as the health-based screening level, per January 25, 2008 letter from EPA to UNC (General Comment 5).

HH = Human Health Standard

I = Irrigation Standard

O = Other Standards for domestic water supply

56007746 (MDJ 10-3-2008)

and 09-6209-SC-91

green = "Comparison Values" column in N.A. Water Systems report (2008b): Calculation of Background Statistics with Comparison Values (also see Appendix Tables B.1 to B.6 in the present report)

**TABLE 3**  
**Identification and Applicability of General Response Actions for Groundwater Remediation**  
 United Nuclear Corporation Church Rock Site, New Mexico

| General Response Actions                              | Description  | Associated Groundwater Remedial Technologies   | Applicability   |
|---|--|--|---|
| No Further Action                                     | No further actions taken at the site to remediate impacted target area(s) (excluding long-term surveillance monitoring by DOE under UMTRCA Title II).                      | None.  | Retained for consideration. Will not meet goals in Zone 3.  |
| Hydraulic Containment with Extraction and Evaporation | Pumping control of impacted are with constituent removal and evaporation.  | Groundwater extraction and evaporation.<br>Directional/horizontal wells.<br>Vertical wells.  | Retained for consideration.<br>See footnote 1.  |
| Enhanced Extraction                                   | Rapid dewatering to reduce volume of impacted water.   | Relatively large number of vertical wells.   | Retained for consideration. May be useful for groundwater containment and rapid mass removal. See footnote 1.   |
| Physical Barriers                                     | Physical or hydraulic barriers to prevent migration of seepage-impacted water.   | Vertical engineered physical barriers.<br>Hydraulic barriers or "fences" from vertical injection-well arrays.  | Zone 3 and Zone 1 are too deep for physical vertical barriers but retained for consideration in Southwest Alluvium (SWA). Hydraulic barriers retained for consideration. May be useful for containment. See footnote 1. |
| Permeable Reactive Barriers (PRBs)                    | Contaminated water is channeled between impervious vertical walls to naturally flow through a permeable reactive barrier where constituents are passively treated in situ. | Overlaps with treatment GRA. Typically emplaced by trenching (excavate-and-fill). Reactive medium sometimes can be emplaced by jetting or hydraulic fracturing.  | Retained for consideration in SWA.  |
| Hydraulic Flushing with Extraction and Evaporation    | Water injection matched with controlled extraction and evaporation.  | Amended injection water for in-situ constituent stabilization plus displacement and extraction of seepage-impacted water.<br>Injection water potentially from deep wells in Dakota Formation or Westwater Canyon Formation.<br>Injection water solely for displacement and extraction of seepage-impacted water. | Retained for consideration in SWA.<br>Injected water will geochemically equilibrate to exceed ROD cleanup levels for sulfate, TDS, and nitrate.   |
| Treatment   | Methods to reduce the mobility, toxicity, or volume of impacted water.   | Alkalinity amendments to injection water for in-situ stabilization and flushing.<br>Reverse osmosis (RO) treatment of injection water for flushing and/or hydraulic barrier.<br>All injection and flushing envisioned as combined with extraction and evaporation.   | Overlaps with flushing and PRB GRAs. RO cost too high to meet demand. Retained for consideration. May be useful for containment or groundwater restoration.   |
| Institutional Controls                                | Legal or governmental controls taken to prevent contact with seepage-impacted water.   | Action and use restrictions.<br>Offsite groundwater monitoring.  | Retained for consideration. Will not meet goals. Can be used as mechanism to prevent contact with water and establish environmental rights-of-way.  |
| Revised Cleanup Standards                             | Background water quality obviates long-term attainment of select EPA 1988 ROD cleanup levels or comparison values outside of Section 2.                                    | None.  | Retained for consideration.   |
| Alternate Concentration Limits                        | As Low As Reasonably Achievable (ALARA) concentrations may require ACLs, alternate abatement standards, or similar regulator decisions.                                    | None. Overlaps with revised cleanup standards GRA.   | Retained for consideration.   |

Note 1: ROD cleanup levels will not be met in any of the three hydrostratigraphic units for sulfate, total dissolved solids, manganese, radium, or nitrate; nickel (Zone 1 and Zone 3); or uranium (SWA, if EPA formally decides to apply the MCL).

**TABLE 4**  
**Summary of Potential Remedial Alternatives for the Southwest Alluvium**  
*Shading Indicates Not Applicable for Further Screening*  
 United Nuclear Corporation Church Rock Site, New Mexico

| Alternative   | Remedial Alternative Description                            | Comments  |
|---------------|---|---|
| Alternative 1 | No Further Action (except for Long-Term Stewardship by DOE) | Source control previously accomplished (USFilter, 2004; GE, 2005); no more tailings seepage. Will not attain select EPA 1988 ROD cleanup levels or comparison values outside of Section 2. See footnote 1. Increasing offsite area of seepage-impacted water has quality better than background water. All offsite hazardous constituents meet ROD cleanup levels within impacted water.  |
| Alternative 2 | Revised Cleanup Standards                                   | Background water quality precludes long-term attainment of select ROD cleanup levels or comparison values outside of Section 2. See footnote 1.   |
| Alternative 3 | Alternate Concentration Limits                              | ACLs to be proposed to meet ALARA goals in accordance with NRC guidance. Attenuation processes are robust (N.A. Water Systems, 2009). See footnote 1.   |
| Alternative 4 | Enhanced Extraction   | Rapid dewatering of seepage-impacted groundwater leaving lower quality background water in its place. All infiltrating water will geochemically equilibrate to exceed ROD cleanup levels for sulfate, TDS, and nitrate. See footnote 1.   |
| Alternative 5 | Vertical Physical Barrier                                   | Only appropriate in combination with upgradient extraction pumping. Slurry wall, grout curtain, sheet piling, or deep-soil mixing are the selected process option alternatives, but concerns exist about sufficient barrier continuity in deeper parts of the alluvium sediments and the likelihood for damage or destruction of the barrier by occasional high-energy flooding and sediment transport.   |
| Alternative 6 | Hydraulic Barrier from Injection Wells                      | Can be used in combination with upgradient extraction pumping. Numerical modeling involving particle tracking is advised to evaluate efficacy of hydraulic barrier. The result would be mixing of the injected and seepage-impacted waters that would produce water that still exceeds the standards. See footnote 1.   |
| Alternative 7 | Permeable Reactive Barriers                                 | PRBs can be emplaced by trenching as part of slurry wall installation as funnels. Vertical barriers defining funnel walls installed as grout curtains or sheet piling do not involve trenching. However, jet grouting of reactive media slurries has been used to emplace PRBs. The particle sizes and viscosity of any such reactive media slurries would have to be carefully evaluated in any potential application to the Southwest Alluvium. A reactive media slurry could be emplaced through deep soil mixing. Concerns exist about sufficient barrier (funnel wall) continuity in deeper parts of the alluvium sediments and the likelihood for damage or destruction of the barrier by occasional high-energy surface water flow and sediment transport. Target contaminants will drive choice of reactive media; e.g., sulfate removal may use organic carbon while radionuclide removal may use zero-valent iron. A bench-scale treatability study is appropriate. Media will become fouled after several years. A key related issue is the potential for EPA to revise cleanup levels with a formal amendment to the ROD. |
| Alternative 8 | Hydraulic Flushing  | Would have to be designed to address the greater than one-mile length of impacted water located upgradient of the southwestern boundary of Section 2. Injected water will geochemically equilibrate to exceed ROD cleanup levels for sulfate, TDS, and nitrate.   |
| Alternative 9 | Hydraulic Containment Using Vertical Pumping Wells          | Background water has higher sulfate and TDS than offsite seepage-impacted water. All waters will geochemically equilibrate to exceed ROD cleanup levels for sulfate, TDS, and nitrate. See footnote 1.  |

Note 1: ROD cleanup levels will not be met for sulfate, total dissolved solids, manganese, radium, or nitrate; or uranium (if EPA formally decides to apply the MCL).

**TABLE 5**  
**Summary of Potential Remedial Alternatives for the Zone 1 Hydrostratigraphic Unit**  
*Shading Indicates Not Applicable for Further Screening*  
 United Nuclear Corporation Church Rock Site, New Mexico

| Alternative   | Remedial Alternative Description                            | Comments   |
|---------------|---|--|
| Alternative 1 | No Further Action (Except for Long-Term Stewardship by DOE) | Source control already accomplished (USFilter, 2004); no more tailings seepage. Former pumping locations met decommissioning criteria. Former pumping did not improve groundwater quality. Decreasing area of seepage-impacted water occurs intrinsically. Offsite hazardous constituents meet ROD cleanup levels and are expected to keep improving.  |
| Alternative 2 | Institutional Controls                                      | Potentially administratively infeasible for Section 1.   |
| Alternative 3 | Revised Cleanup Standards                                   | Background water quality precludes long-term attainment of select EPA 1988 ROD cleanup levels or comparison values outside of Section 2. See footnote 1.   |
| Alternative 4 | Alternate Concentration Limits                              | ACLs to be proposed to meet ALARA goals in accordance with NRC guidance. Zone 1 ACL Application submitted to NRC in December 2008 (N.A. Water Systems, 2008d). Attenuation processes are robust (N.A. Water Systems, 2009). A key related issue is the potential for EPA to revise cleanup levels with a formal amendment to the ROD.  |
| Alternative 5 | Hydraulic Containment with Extraction and Evaporation.      | Extraction well history indicates it is not possible to full desaturate Zone 1 by pumping – some impacted water will remain. ALARA demonstration test and long-term groundwater quality data indicate that pumping did not improve water quality.  |
| Alternative 6 | Enhanced Extraction   | Rapid dewatering of seepage-impacted groundwater. Within UNC Section 2 property, only a very narrow strip of land exists between the eastern edge of the Central Cell and the western boundary of Section 1 to the east; not well suited for large number of extraction wells. Extraction well decommissioning history indicates it is not possible to fully desaturate Zone 1 by pumping – some impacted water will remain. |

Note 1: ROD cleanup levels will not be met for sulfate, total dissolved solids, manganese, radium, nitrate, or nickel.



**TABLE 6**  
**Summary of Potential Remedial Alternatives for the Zone 3 Hydrostratigraphic Unit**  
*Shading Indicates Not Applicable for Further Screening*  
 United Nuclear Corporation Church Rock Site, New Mexico

| Alternative   | Remedial Alternative Description                             | Comments   |
|---------------|--|--|
| Alternative 1 | No Further Action (Except for Long-Term Stewardship by DOE). | Source control already accomplished (USFilter, January 2004); no more tailings seepage.<br>Will not attain select EPA 1988 ROD cleanup levels or comparison values outside of Section 2. See footnote 1.   |
| Alternative 2 | Institutional Controls (ICs) for Section 36 if Needed.       | ICs for Section 36 (UNC property outside of Section 2) have not yet been formally proposed.<br>Appendix H of ROD (Responsiveness Summary), Response to Comment 6 states: "The exact area to be deeded to the Department of Energy has not been determined."  |
| Alternative 3 | Revised Cleanup Standards.                                   | Background water quality precludes long-term attainment of select EPA 1988 ROD cleanup levels or comparison values outside of Section 2. See footnote 1.   |
| Alternative 4 | Alternate Concentration Limits.                              | ACLs to be proposed to meet ALARA goals in accordance with NRC guidance.<br>A key related issue is the potential for EPA to revise cleanup levels with a formal amendment to the ROD.  |
| Alternative 6 | Hydraulic Containment with Extraction and Evaporation.       | This is the current remedy in Zone 3.<br>Extraction well history indicates it is not possible to fully desaturate Zone 3 by pumping – some impacted water will remain. See footnote 1.<br>Merits of extraction with evaporation using spray misters into ponds were addressed by UNC contribution to Appendix H of the EPA 1988 Feasibility Study. |
| Alternative 7 | Enhanced Extraction.   | Rapid dewatering of seepage-impacted groundwater.<br>Extraction well history indicates it is not possible to fully desaturate Zone 3 by pumping – some impacted water will remain. See footnote 1.   |
| Alternative 8 | Hydraulic Barrier from Injection Wells for Containment.      | Downgradient hydraulic barrier requires sufficient source of high quality water.<br>Only some of the hydraulic barrier injection water would be recovered; some will flow north onto Navajo land.<br>Based on previous pilot testing, this formation may not be amenable to injection. See footnote 1.   |

Note 1: ROD cleanup levels will not be met for sulfate, total dissolved solids, manganese, radium, nitrate, nickel, arsenic, cobalt, or molybdenum.

# Figures

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**FIGURE 1**  
**Screening of Technology and Process Options**  
*Shading Indicates Not Applicable for Further Screening*  
 United Nuclear Corporation Church Rock Site, New Mexico

| General Response Actions                              | Remedial Technology  | Process Option  | Technical and Administrative Implementability Screening Comments  |
|---|--|---|---|
| No Further Action                                     | None   | Not Applicable  | Required for consideration by National Contingency Plan. Potentially applicable in Southwest Alluvium (SWA) and Zone 1. <b>Eliminated for Zone 3 because it will not meet remediation goals.</b>  |
| Hydraulic Containment with Extraction and Evaporation | Groundwater Extraction + Evaporation + Containment Analysis  | Vertical Wells  | Potentially applicable. Most similar to current remedy. See footnote 1.   |
|   |  | Directional Wells   | <b>In Zone 3, unreliable performance due to high probability of well failure (collapse or encrustation). Would require at least two redundant wells resulting in excessive cost. Technically infeasible for SWA and Zone 1.</b>                           |
|   |  | Tunnels   | <b>Excessive cost. Inability to effectively manage large volumes of generated waste material.</b>   |
| Enhanced Extraction                                   | Relatively Large Number of Vertical Wells + Extraction + Evaporation   | Vertical Wells  | Potentially applicable. See footnote 1.   |
| Physical Barriers                                     | Vertical Physical Barriers   | Soil-Bentonite Slurry Wall  | Potentially applicable in SWA if combined with either PRB (combines with treatment GRA) or new extraction pumping to avoid spillover of barrier. See footnote 1.  |
|   |  | Cement-Bentonite Slurry Wall                                      |   |
|   |  | Vibrating Beam  |   |
|   |  | Grout Curtains  |   |
|   |  | Sheet Piling  |   |
|   |  | Chemical Grouting   |   |
|   |  | Ground Freezing   |   |
|   | Deep Soil Mixing   |   |   |
|   | Hydraulic Barriers from Injection Wells  | Arrays of Vertical Injection Wells                                | Potentially applicable in SWA and Zone 3; can be combined with extraction pumping. See footnote 1.  |
| Permeable Reactive Barriers                           | Passive In-Situ Treatment  | Funnel and Reactive-Medium Gate System                            | Potentially applicable in SWA; combines with Treatment GRA. Bench-scale treatability study is appropriate.  |
| Hydraulic Flushing with Extraction and Evaporation    | Alkalinity-Amended Injection Water   | Arrays of Vertical Injection Wells                                | <b>Combines with Treatment GRA. Zone 3 infeasibility suggested by in-situ alkalinity stabilization pilot study. Infeasible for Zone 1. Not applicable for relatively alkaline waters of SWA.</b>  |
|   | Injection Water from Deep Wells in Dakota Formation or Westwater Canyon Formation, to Meet State Water Quality Standards | Arrays of Vertical Injection Wells                                | Potentially applicable in SWA. Injected water will geochemically equilibrate to exceed ROD cleanup levels for sulfate, TDS, and nitrate. Based on previous pilot testing Zone 3 may not be amenable to injection, but retained as potentially applicable. |
| Treatment   | Injection + In-Situ Treatment + Flushing + Extraction + Evaporation  | Alkalinity Amendments to Injection Waters                         | <b>Zone 3 infeasibility suggested by in-situ alkalinity stabilization pilot study. Infeasible for Zone 1. Not applicable for relatively alkaline waters of SWA.</b>   |
|   | Pre-Injection Water Purification + Injection + Flushing + Extraction   | Reverse Osmosis Treatment of Injection Waters                     | <b>Excessive cost to meet demand.</b>   |
| Institutional Controls                                | Access and Use Restrictions  | Navajo Tribal Land-Use Restrictions<br>Environmental Right-of-Way | Navajo have not responded (since February 2000) on proposed tribal resolution and environmental right-of-way for offsite monitoring.  |
|   | Monitoring   | Offsite Groundwater Monitoring                                    | Applicable for UNC property when turned over to DOE.  |
| Revised Cleanup Standards                             | None   | None  | Potentially applicable.   |
| Alternate Concentration Limits                        | None   | None  | Potentially applicable.   |

Note 1: ROD cleanup levels will not be met in any of the three hydrostratigraphic units for sulfate, total dissolved solids, manganese, radium, or nitrate; nickel (Zone 1 and Zone 3); or uranium (SWA, if EPA formally decides to apply the MCL).

**FIGURE 2**  
**Selection of Representative Process Options**  
 United Nuclear Corporation Church Rock Site, New Mexico

| General Response Actions                              | Remedial Technology  | Process Option  | Summary of Effectiveness, Implementability, Cost Screening   |
|---|--|---|--|
| No Further Action                                     | None   | Not Applicable  | Required for consideration by National Contingency Plan. Potentially applicable in Southwest Alluvium (SWA) and Zone 1. Will not alleviate continued plume migration in Zone 3.<br>Monitoring costs only.  |
| Hydraulic Containment with Extraction and Evaporation | Groundwater Extraction + Evaporation + Containment Analysis          | Vertical Wells  | Most similar to current remedy in Zone 3. Potentially effective for removal of all contaminants in impacted water, but will not address background water quality (see footnote 1). Site history indicates Zone 1 and Zone 3 extraction wells usually have effective durations of a few years. Site history has demonstrated effectiveness of evaporation for treatment of impacted water.<br>Moderate cost, moderate operations & maintenance (O&M).                         |
| Enhanced Extraction                                   | Relatively Large Number of Vertical Wells + Extraction + Evaporation | Vertical Wells  | Potentially applicable to SWA and Zone 3. Potentially effective for removal of all contaminants in impacted water, but will not address background water quality issues (see footnote 1). Site history indicates Zone 3 extraction wells usually have effective durations of a few years. Site history has demonstrated effectiveness of evaporation for treatment of impacted water.<br>Potentially high cost, high O&M.  |
| Physical Barriers                                     | Hydraulic Barriers from Injection Wells                              | Arrays of Vertical Injection Wells                                | Potentially applicable in Zone 3; can be combined with extraction pumping. Potentially effective for hydraulic containment of impacted water. See footnote 1. Water source has not been established.<br>If one or more new deep supply wells required, high cost, moderate O&M.  |
| Institutional Controls                                | Access and Use Restrictions  | Navajo Tribal Land-Use Restrictions<br>Environmental Right-of-Way | Potentially applicable in SWA and Zone 1. Means to prevent access to impacted water and background water. Navajo have not responded (since February 2000) on proposed tribal resolution and environmental right-of-way for offsite monitoring. Effectiveness depends on future implementation. Implementability is a function of legal requirements.<br>Applicable for UNC property when turned over to DOE.<br>Potentially negligible cost to relatively low cost, low O&M. |
|   | Monitoring   | Offsite Groundwater Monitoring                                    | Effective for determining performance of remedial alternatives. Potentially administratively infeasible. Implementable.<br>Relatively low cost, low O&M.   |
| Revised Cleanup Standards                             | None   | None  | Implementation depends on stakeholder agreements. Potentially effective in contributing to eventual closure of site corrective action. Effectiveness depends on future implementation. Relatively low administrative costs.  |
| Alternate Concentration Limits                        | None   | None  | Implementation depends on stakeholder agreements. Potentially effective in contributing to eventual closure of site corrective action. Effectiveness depends on future implementation. Relatively low administrative costs.  |

Note 1: ROD cleanup levels will not be met in any of the three hydrostratigraphic units for sulfate, total dissolved solids, manganese, radium, or nitrate; nickel (Zone 1 and Zone 3); or uranium (SWA, if EPA decides to apply the MCL).

**FIGURE 3**  
**Summary of Response Actions, Technologies and Representative Process Options Selected for Further Development**  
 United Nuclear Corporation Church Rock Site, New Mexico

| Response Actions                | Technologies and Representative Process Options   | Use of Response Actions, Technologies, Process Options in Developing Remedial Alternatives  | Shading Indicates Used Together For Groundwater Remedial Alternatives |
|---------------------------------|---|---|---|
| No Further Action               |   | Used alone as a no further action alternative. Applicability varied by hydrostratigraphic unit.   |   |
| Institutional Controls          | Access and use restrictions. Offsite groundwater monitoring.  | Used together as an institutional control alternative. Applicability varied by hydrostratigraphic unit.   |   |
| Modified Site Cleanup Standards |   | Revised cleanup standards and/or alternate concentration limits; used together or separately. Applicability varied by hydrostratigraphic unit. See footnote 1.      |   |
| Physical Barriers               | Hydraulic barriers from arrays of vertical injection wells.   | Used for hydraulic containment of contaminated groundwater. Configuration varied by remediation program and hydrostratigraphic unit. See footnote 1.                |   |
| Hydraulic Containment           | Extraction + evaporation + containment analysis. Vertical wells.                                      | Used for extraction of contaminated groundwater + removal of contaminants. Configuration varied by remediation program and hydrostratigraphic unit. See footnote 1. |   |
| Enhanced Extraction             | Relatively large areas of simultaneous extraction pumping + extraction + evaporation. Vertical wells. | Used for extraction of contaminated groundwater + removal of contaminants. Configuration varied by remediation program and hydrostratigraphic unit. See footnote 1. |   |
| Institutional Controls          | Access and use restrictions. Offsite groundwater monitoring.  | Used in combination to monitor remedial progress, determine extent of contamination, prevent contaminated groundwater use.  |   |

Note 1: ROD cleanup levels will not be met in any of the three hydrostratigraphic units for sulfate, total dissolved solids, manganese, radium, or nitrate; nickel (Zone 1 and Zone 3); or uranium (SWA, if EPA formally decides to apply the MCL).

**FIGURE 4**  
**Combined Remedial Alternatives**  
*Shading Indicates Components INCLUDED in Alternative*  
 United Nuclear Corporation Church Rock Site, New Mexico

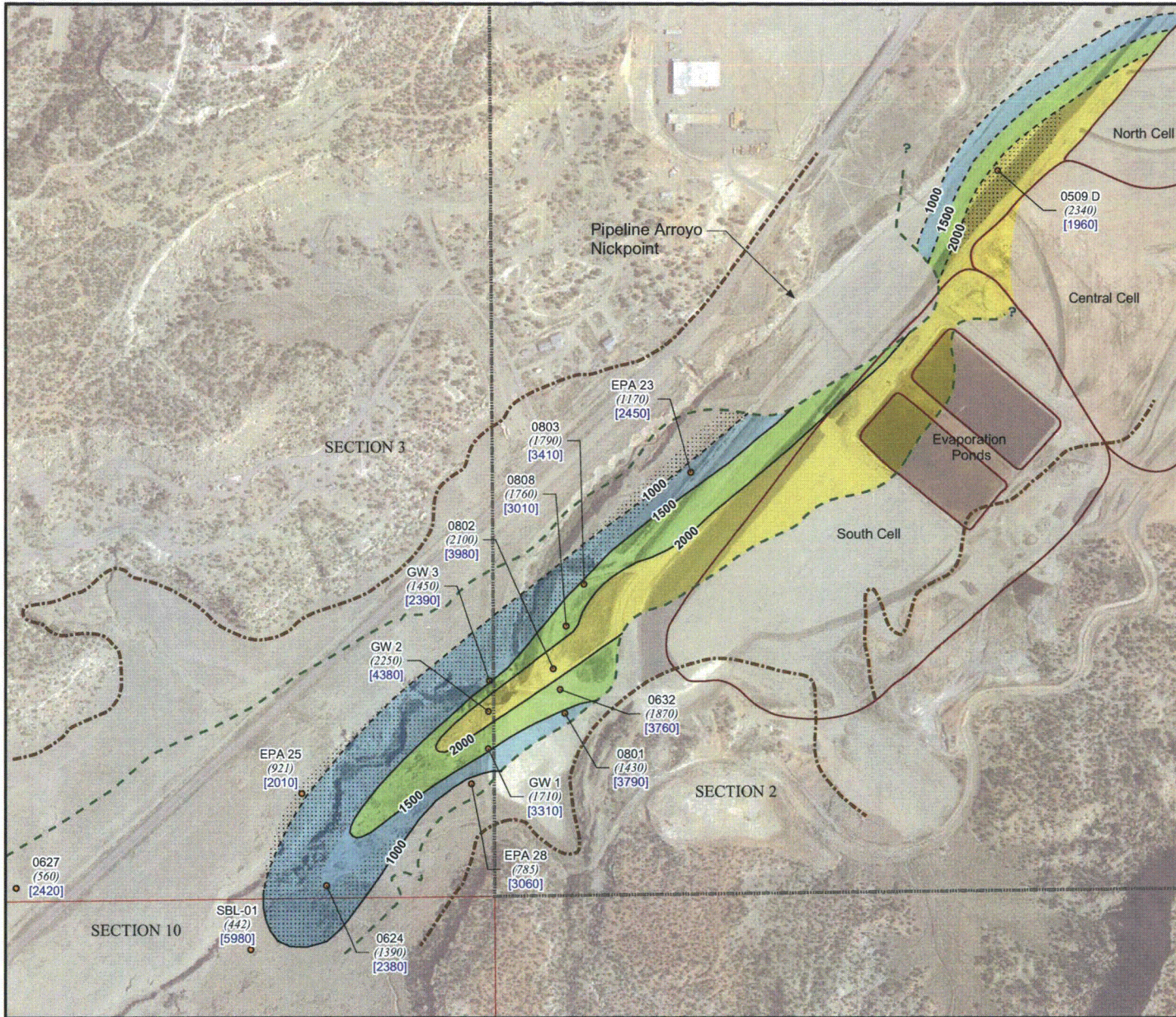
| COMBINED<br>REMEDIAL<br>ALTERNATIVES   | COMPONENTS OF COMBINED REMEDIAL ALTERNATIVES |        |             |            |                        |         |                         |        |             |            |                        |         |                         |        |             |            |                        |         |             |
|--|--|--------|-------------|------------|------------------------|---------|-------------------------|--------|-------------|------------|------------------------|---------|-------------------------|--------|-------------|------------|------------------------|---------|-------------|
|  | SOUTHWEST ALLUVIUM (SWA)                     |        |             |            |                        |         | ZONE 3                  |        |             |            |                        |         | ZONE 1                  |        |             |            |                        |         | Evaporation |
|  | No<br>Further<br>Action                      | ICs    | Containment | Extraction | Enhanced<br>Extraction | Barrier | No<br>Further<br>Action | ICs    | Containment | Extraction | Enhanced<br>Extraction | Barrier | No<br>Further<br>Action | ICs    | Containment | Extraction | Enhanced<br>Extraction | Barrier |             |
| No Further Action  | Shaded                                       |        |             |            |                        |         |                         |        |             |            |                        |         |                         |        |             |            |                        |         |             |
| Institutional<br>Controls (ICs)  |  | Shaded |             |            |                        |         |                         | Shaded |             |            |                        |         |                         |        |             |            |                        |         |             |
| 1. Hydraulic Containment and<br>Extraction Onsite in SWA and<br>Zone 3                                   |  |        | Shaded      | Shaded     |                        |         |                         |        | Shaded      | Shaded     |                        |         |                         |        |             |            |                        |         |             |
| 2. Hydraulic Containment and<br>Extraction Onsite in SWA and<br>Zone 3; ICs Offsite in SWA and<br>Zone 1 |  | Shaded | Shaded      | Shaded     |                        |         |                         |        | Shaded      | Shaded     |                        |         |                         | Shaded |             |            |                        |         |             |
| 3. Enhanced Extraction Onsite<br>in SWA and Zone 3; ICs Offsite<br>in SWA and Zone 1                     |  | Shaded |             |            | Shaded                 |         |                         |        |             |            | Shaded                 |         |                         | Shaded |             |            |                        |         |             |
| 4. Hydraulic Barrier<br>Containment and Extraction<br>Onsite in Zone 3; ICs Offsite in<br>SWA and Zone 1 |  | Shaded |             |            |                        |         |                         |        | Shaded      | Shaded     |                        | Shaded  |                         | Shaded |             |            |                        |         |             |

Note: EPA views ICs as potentially useful if the Navajo Nation concurs. Otherwise, EPA has indicated it can proceed with remedy modification absent ICs (as discussed at the multi-agency technical meeting held on May 5, 2005, at the Church Rock site).

# Appendices

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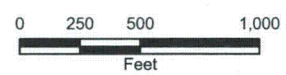
## Appendix A Figures A.1 to A.3



**Legend**

- Southwest Alluvium Well
  - - - Approximate Extent of Saturated Alluvium
  - - - - Approximate Extent of Alluvium
  - Bicarbonate Isoconcentration Contour in mg/L
  - - - - Inferred Bicarbonate Isoconcentration Contour in mg/L
- Bicarbonate Concentrations (mg/L)**
- 1000 - 1500
  - 1500 - 2000
  - >2000
- Property Boundary
  - Section Boundary
  - Tailings Pond
  - Stippled Sulfate Below 2125 mg/L
- (2350) Bicarbonate result in mg/L  
[3580] Sulfate result in mg/L

- Notes:**
1. Well names are displayed with black text.
  2. Aerial photo taken on August 1, 1996.

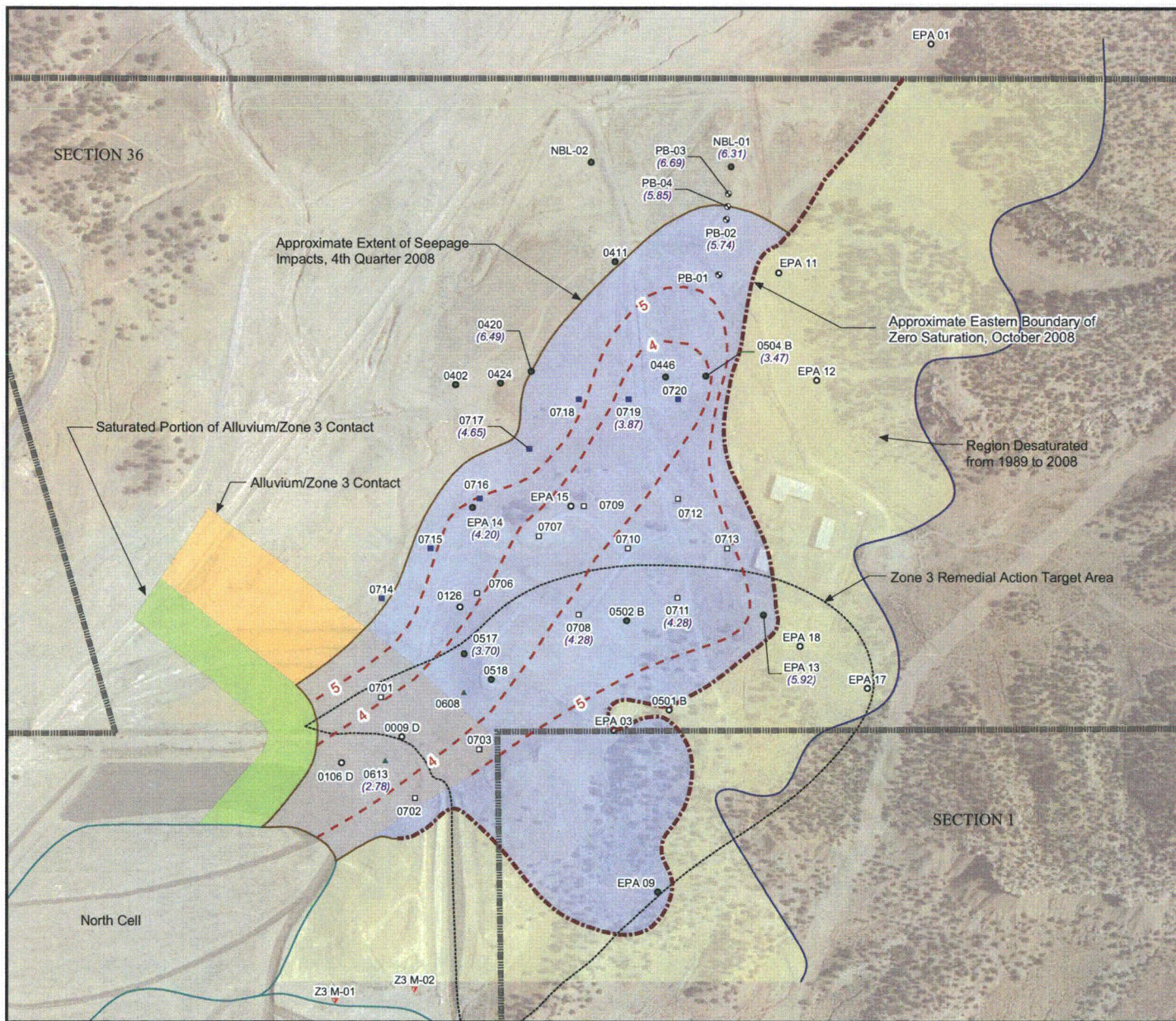


**FIGURE A.1**  
Southwest Alluvium Bicarbonate Isoconcentration Map and Distribution of Sulfate Below 2125 mg/L, October 2008

United Nuclear Corporation Church Rock Site,  
Church Rock, New Mexico







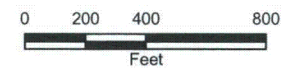
**Legend**

- Property Boundary
- Zone 3 Target Remedial Action Area
- Section Boundary
- Cell Boundary
- Approximate Area Impacted by Tailings Seepage

**Well Type**

- Monitoring
- Dry Monitoring
- Stage I Extraction
- Stage II Extraction
- Plume Boundary
- Northeast Pump-Back
- Piezometer
- Approximate Eastern Boundary of Zero Saturation
- pH contour

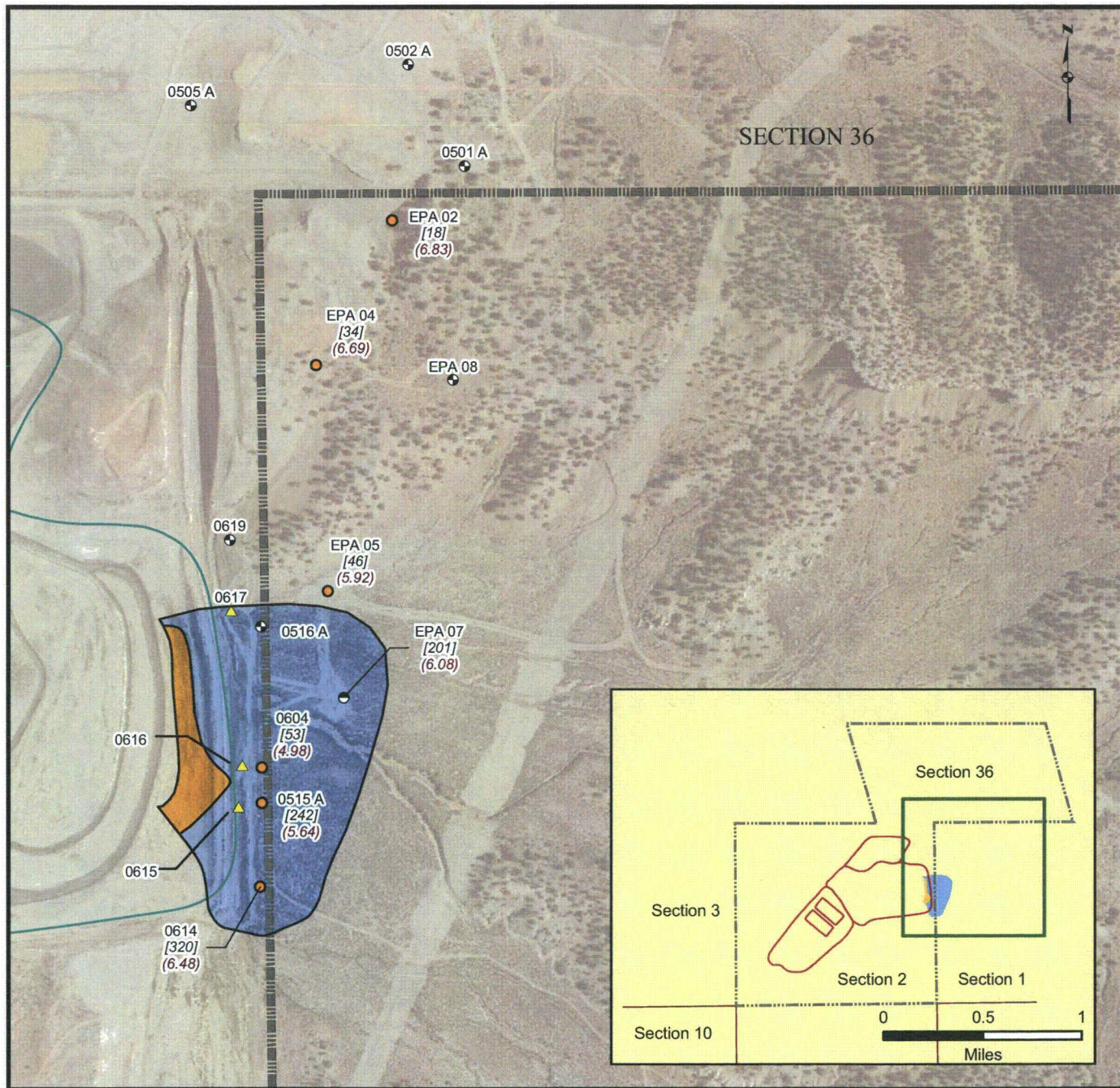
- Notes:**
- Well names are displayed with black text.
  - Values for field measured pH are shown with purple text and enclosed in parentheses.
  - Aerial photo taken on August 1, 1996.



**FIGURE A.2**  
Zone 3 Approximate Extent of Seepage Impacts, October 2008

United Nuclear Corporation Church Rock Site,  
Church Rock, New Mexico





**Legend**

**Well Type**

- Water Quality and Water Level Monitoring
- ⊕ Water Level Monitoring
- ⊖ Decommissioned East Pump Back
- ▲ Revised East Pump Back (Inactive)

     Cell Boundary

     Property Boundary

Approximate Extent of Zone 1 Seepage Impact

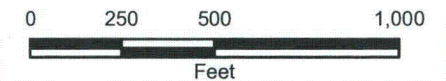
Approximate Extent of Zone 1 pH Less Than 4.0

[71] Chloride result in mg/L

(6.03) Field-measured pH in SU

**Notes:**

1. Seepage impacts delineated by chloride detections greater than 50 mg/L.
2. Aerial photo taken on August 1, 1996.



**FIGURE A.3**  
 Depiction of Zone 1  
 Extent of Seepage Impacts,  
 October 2008

United Nuclear Corporation Church Rock Site,  
 Church Rock, New Mexico



# Appendices

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## Appendix B Tables B.1 to B.6

**TABLE B.1**  
**Summary Statistics for COPCs and Trace Metals in Southwest Alluvium Background Groundwater**

| Parameter   | Units | Total Data | Percent Nondetect | Minimum Detected | Maximum Detected | Mean of Detected | Median of Detected | UCL95 of Mean |
|-------------|-------|------------|-------------------|------------------|------------------|------------------|--------------------|---------------|
| Al          | mg/L  | 391        | 94.6%             | 0.1              | 0.6              | 0.182            | 0.14               | 0.107         |
| As          | mg/L  | 391        | 93.1%             | 0.001            | 0.01             | 0.00237          | 0.001              | 0.00116       |
| Be          | mg/L  | 389        | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cd          | mg/L  | 391        | 96.9%             | 0.006            | 0.07             | 0.0255           | 0.01               | 0.0108        |
| Co          | mg/L  | 391        | 81.6%             | 0.01             | 0.06             | 0.0186           | 0.02               | 0.0121        |
| Pb          | mg/L  | 388        | 99.5%             | 0.05             | 0.07             | 0.06             | 0.06               | 0.0502        |
| Mn          | mg/L  | 389        | 11.8%             | 0.01             | 3.35             | 0.339            | 0.13               | 0.414         |
| Mo          | mg/L  | 391        | 99.5%             | 0.03             | 0.03             | N/A              | N/A                | N/A           |
| Ni          | mg/L  | 391        | 96.4%             | 0.05             | 0.17             | 0.08             | 0.08               | 0.0613        |
| Se          | mg/L  | 390        | 50.5%             | 0.001            | 0.195            | 0.00708          | 0.003              | 0.00516       |
| V           | mg/L  | 391        | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cl          | mg/L  | 391        | 0.0%              | 9.8              | 169              | 74.82            | 67.8               | 83.72         |
| SO4         | mg/L  | 391        | 0.0%              | 605              | 5830             | 2401             | 2420               | 2468          |
| NO3_as_N    | mg/L  | 391        | 1.3%              | 0.09             | 1225             | 99.54            | 74.1               | 137.4         |
| U           | mg/L  | 390        | 0.3%              | 0.001            | 0.367            | 0.0419           | 0.031              | 0.0459        |
| Chloroform  | ug/L  | 391        | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Lab_TDS     | mg/L  | 390        | 0.0%              | 1310             | 10530            | 4630             | 4795               | 4745          |
| Rad-226     | pCi/L | 391        | 34.3%             | 0.2              | 9.4              | 0.979            | 0.6                | 0.798         |
| Rad-228     | pCi/L | 391        | 67.8%             | 1                | 7                | 2.55             | 2.2                | 1.611         |
| Rad_totl    | pCi/L | 391        | 25.3%             | 0.2              | 12               | 1.9              | 1.3                | 1.621         |
| Th-230      | pCi/L | 391        | 91.8%             | 0.2              | 14.3             | 2.841            | 1.6                | 0.509         |
| Pb-210      | pCi/L | 391        | 78.3%             | 1                | 14.2             | 2.845            | 2.2                | 1.513         |
| Gross_Alpha | pCi/L | 391        | 70.6%             | 0.4              | 17.8             | 3.35             | 2.1                | 1.693         |
| Sb          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ba          | mg/L  | 26         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cr          | mg/L  | 37         | 97.3%             | 0.29             | 0.29             | N/A              | N/A                | N/A           |
| Cu          | mg/L  | 13         | 84.6%             | 0.01             | 0.01             | N/A              | N/A                | N/A           |
| Fe          | mg/L  | 19         | 79.0%             | 0.06             | 1.4              | 0.418            | 0.105              | 0.275         |
| Hg          | mg/L  | 8          | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ag          | mg/L  | 21         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Tl          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Zn          | mg/L  | 25         | 40.0%             | 0.02             | 0.429            | 0.0891           | 0.05               | 0.0949        |

TABLE B.2

Summary comparisons of Parameter Concentrations in Southwest Alluvium Background Groundwater to Comparison Values

| Parameter   | Units | Comparison Value <sup>1</sup> |                     |         |           |             |              | Single Sample Hypothesis Test <sup>3</sup><br>H0: Site Median >= CV |                 | Potential Background Level |
|-------------|-------|-------------------------------|---------------------|---------|-----------|-------------|--------------|---|-----------------|----------------------------|
|             |       |                               | Max RL <sup>2</sup> | UCL95   | UCL95>CV? | Max RL>=CV? | Percent < RL | Sign Test   | Wilcoxon Signed |                            |
| Al          | mg/L  | 5                             | 0.1                 | 0.107   | NO        | NO          | 95%          | Reject  | Reject          |                            |
| As          | mg/L  | 0.01                          | 0.001               | 0.00116 | NO        | NO          | 93%          | Reject  | Reject          |                            |
| Be          | mg/L  | 0.004                         | 0.1                 | NA      | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cd          | mg/L  | 0.005                         | 0.01                | 0.0108  | YES       | YES         | 97%          | Do not Reject   | Reject          | 0.0108                     |
| Co          | mg/L  | 0.05                          | 0.01                | 0.0121  | NO        | NO          | 82%          | Reject  | Reject          |                            |
| Pb          | mg/L  | 0.05                          | 0.05                | 0.0502  | YES       | YES         | 99%          | Do not Reject   | Reject          | 0.0502                     |
| Mn          | mg/L  | 0.2                           | 0.01                | 0.414   | YES       | NO          | 12%          | Reject  | Reject          | 0.414                      |
| Mo          | mg/L  | 1                             | 0.1                 | NA      | N/A       | NO          | 99%          | Reject  | Reject          |                            |
| Ni          | mg/L  | 0.2                           | 0.05                | 0.0613  | NO        | NO          | 96%          | Reject  | Reject          |                            |
| Se          | mg/L  | 0.05                          | 0.001               | 0.00516 | NO        | NO          | 51%          | Reject  | Reject          |                            |
| V           | mg/L  | 0.1                           | 0.1                 | NA      | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cl          | mg/L  | 250                           | N/A                 | 83.72   | NO        | N/A         | 0%           | Reject  | Reject          |                            |
| SO4         | mg/L  | 2125                          | N/A                 | 2468    | YES       | N/A         | 0%           | Do not Reject   | Do not Reject   | 2468                       |
| NO3_as_N    | mg/L  | 30                            | 0.1                 | 137.4   | YES       | NO          | 1%           | Do not Reject   | Do not Reject   | 137.4                      |
| U           | mg/L  | 0.03                          | 0.0003              | 0.0459  | YES       | NO          | 0%           | Do not Reject   | Do not Reject   | 0.0459                     |
| Chloroform  | ug/L  | 80                            | 1                   | NA      | N/A       | NO          | 100%         | N/A   | N/A             |                            |
| Lab_TDS     | mg/L  | 3170                          | N/A                 | 4745    | YES       | N/A         | 0%           | Do not Reject   | Do not Reject   | 4745                       |
| Rad_totl    | pCi/L | 5                             | 0.2                 | 1.621   | NO        | NO          | 25%          | Reject  | Reject          |                            |
| Th-230      | pCi/L | 5                             | 0.2                 | 0.509   | NO        | NO          | 92%          | Reject  | Reject          |                            |
| Pb-210      | pCi/L | 1                             | 1                   | 1.513   | YES       | YES         | 78%          | Do not Reject   | Reject          | 1.513                      |
| Gross_Alpha | pCi/L | 15                            | 1                   | 1.693   | NO        | NO          | 71%          | Reject  | Reject          |                            |
| Sb          | mg/L  | 0.006                         | N/A                 | NA      | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Ba          | mg/L  | 2                             | 0.1                 | NA      | N/A       | NO          | 100%         | Reject  | Reject          |                            |
| Cr          | mg/L  | 0.05                          | 0.05                | NA      | N/A       | YES         | 97%          | Reject  | Reject          |                            |
| Cu          | mg/L  | 1                             | 0.02                | NA      | N/A       | NO          | 85%          | Reject  | Reject          |                            |
| Fe          | mg/L  | 1                             | 0.1                 | 0.275   | NO        | NO          | 79%          | Reject  | Reject          |                            |
| Hg          | mg/L  | 0.002                         | 0.001               | NA      | N/A       | NO          | 100%         | N/A   | N/A             |                            |
| Ag          | mg/L  | 0.05                          | 0.05                | NA      | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Tl          | mg/L  | 0.002                         | N/A                 | NA      | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Zn          | mg/L  | 10                            | 0.1                 | 0.0949  | NO        | NO          | 40%          | Reject  | Reject          |                            |

**Note:**

1. See Table 1 for sources of Comparison Values (CV)
2. RL is an abbreviation of reporting limit
3. Single sample hypotheses tests are not applicable to datasets having 100% censored data

**TABLE B.3**  
**Summary Statistics for COPCs and Trace Metals in Zone 1 Background Groundwater**

| Parameter   | Units | Total Data | Percent Nondetect | Minimum Detected | Maximum Detected | Mean of Detected | Median of Detected | UCL95 of Mean |
|-------------|-------|------------|-------------------|------------------|------------------|------------------|--------------------|---------------|
| Al          | mg/L  | 234        | 86.8%             | 0.1              | 0.6              | 0.185            | 0.14               | 0.117         |
| As          | mg/L  | 234        | 83.8%             | 0.001            | 0.004            | 0.00174          | 0.002              | 0.00117       |
| Be          | mg/L  | 234        | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cd          | mg/L  | 234        | 98.7%             | 0.005            | 0.01             | 0.00733          | 0.007              | 0.0051        |
| Co          | mg/L  | 234        | 89.7%             | 0.01             | 0.06             | 0.0171           | 0.01               | 0.0112        |
| Pb          | mg/L  | 234        | 99.6%             | 0.05             | 0.05             | N/A              | N/A                | N/A           |
| Mn          | mg/L  | 234        | 0.4%              | 0.66             | 4.15             | 2.434            | 2.65               | 2.519         |
| Mo          | mg/L  | 234        | 97.9%             | 0.03             | 0.27             | 0.12             | 0.13               | 0.132         |
| Ni          | mg/L  | 230        | 98.7%             | 0.06             | 0.07             | 0.0667           | 0.07               | 0.0602        |
| Se          | mg/L  | 234        | 95.7%             | 0.001            | 0.004            | 0.0019           | 0.0015             | 0.00107       |
| V           | mg/L  | 234        | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cl          | mg/L  | 234        | 0.0%              | 19.4             | 252              | 37.13            | 37.9               | 39.03         |
| SO4         | mg/L  | 234        | 0.0%              | 1410             | 3882             | 2703             | 2952               | 2773          |
| NO3_as_N    | mg/L  | 233        | 71.7%             | 0.01             | 51.8             | 1.767            | 0.16               | 1.754         |
| U           | mg/L  | 233        | 16.7%             | 0.0004           | 0.975            | 0.00862          | 0.0013             | 0.0255        |
| Chloroform  | ug/L  | 234        | 99.6%             | 0.91             | 0.91             | N/A              | N/A                | N/A           |
| Lab_TDS     | mg/L  | 234        | 0.0%              | 2490             | 5610             | 4225             | 4569               | 4319          |
| Rad-226     | pCi/L | 233        | 1.7%              | 0.2              | 5.4              | 1.269            | 1.2                | 1.314         |
| Rad-228     | pCi/L | 234        | 29.9%             | 1                | 13.8             | 3.457            | 3.1                | 2.946         |
| Rad_totl    | pCi/L | 234        | 0.9%              | 0.2              | 14.8             | 3.618            | 3.35               | 3.841         |
| Th-230      | pCi/L | 234        | 91.9%             | 0.2              | 4.9              | 0.974            | 0.7                | 0.403         |
| Pb-210      | pCi/L | 234        | 80.8%             | 1.1              | 9.1              | 2.58             | 2.1                | 1.579         |
| Gross_Alpha | pCi/L | 234        | 35.0%             | 0.9              | 14               | 2.757            | 2                  | 2.361         |
| Sb          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ba          | mg/L  | 14         | 78.6%             | 0.079            | 0.091            | 0.0847           | 0.084              | 0.091         |
| Cr          | mg/L  | 11         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cu          | mg/L  | 4          | 75.0%             | 0.026            | 0.026            | N/A              | N/A                | N/A           |
| Fe          | mg/L  | 12         | 8.3%              | 0.25             | 14               | 6.386            | 6.2                | 8.701         |
| Hg          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ag          | mg/L  | 11         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Tl          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Zn          | mg/L  | 16         | 56.3%             | 0.01             | 5                | 0.784            | 0.046              | 3.583         |

**TABLE B.4**  
**Summary Comparisons of Parameter Concentrations in Zone 1 Background Groundwater to Comparison Values**

| Parameter   | Units | Comparison Value <sup>1</sup> |                     |         |           |             |              | Single Sample Hypothesis Test <sup>3</sup><br>H0: Site Median >= CV |                 | Potential Background Level |
|-------------|-------|-------------------------------|---------------------|---------|-----------|-------------|--------------|---|-----------------|----------------------------|
|             |       |                               | Max RL <sup>2</sup> | UCL95   | UCL95>CV? | Max RL>=CV? | Percent < RL | Sign Test   | Wilcoxon Signed |                            |
| Al          | mg/L  | 5                             | 0.1                 | 0.117   | NO        | NO          | 87%          | Reject  | Reject          |                            |
| As          | mg/L  | 0.01                          | 0.001               | 0.00117 | NO        | NO          | 84%          | Reject  | Reject          |                            |
| Be          | mg/L  | 0.004                         | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cd          | mg/L  | 0.005                         | 0.01                | 0.0051  | YES       | YES         | 99%          | Do not Reject   | Reject          | 0.0051                     |
| Co          | mg/L  | 0.05                          | 0.01                | 0.0112  | NO        | NO          | 90%          | Reject  | Reject          |                            |
| Pb          | mg/L  | 0.05                          | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Mn          | mg/L  | 0.2                           | 0.01                | 2.519   | YES       | NO          | 0%           | Do not Reject   | Do not Reject   | 2.519                      |
| Mo          | mg/L  | 1                             | 0.1                 | 0.132   | NO        | NO          | 98%          | Reject  | Reject          |                            |
| Ni          | mg/L  | 0.2                           | 0.05                | 0.0602  | NO        | NO          | 99%          | Reject  | Reject          |                            |
| Se          | mg/L  | 0.05                          | 0.001               | 0.00107 | NO        | NO          | 96%          | Reject  | Reject          |                            |
| V           | mg/L  | 0.1                           | 0.1                 | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cl          | mg/L  | 250                           | N/A                 | 39.03   | NO        | N/A         | 0%           | Reject  | Reject          |                            |
| SO4         | mg/L  | 2125                          | N/A                 | 2773    | YES       | N/A         | 0%           | Do not Reject   | Do not Reject   | 2773                       |
| NO3_as_N    | mg/L  | 30                            | 0.1                 | 1.754   | NO        | NO          | 72%          | Reject  | Reject          |                            |
| U           | mg/L  | 0.03                          | 0.0004              | 0.0255  | NO        | NO          | 17%          | Reject  | Reject          |                            |
| Chloroform  | ug/L  | 80                            | 1                   | N/A     | N/A       | N/A         | 100%         | N/A   | N/A             |                            |
| Lab_TDS     | mg/L  | 3170                          | N/A                 | 4319    | YES       | N/A         | 0%           | Do not Reject   | Do not Reject   | 4319                       |
| Rad_totl    | pCi/L | 5                             | 0.2                 | 3.841   | NO        | NO          | 1%           | Reject  | Reject          |                            |
| Th-230      | pCi/L | 5                             | 0.2                 | 0.403   | NO        | NO          | 92%          | Reject  | Reject          |                            |
| Pb-210      | pCi/L | 1                             | 1                   | 1.579   | YES       | YES         | 81%          | Do not Reject   | Reject          | 1.579                      |
| Gross Alpha | pCi/L | 15                            | 1                   | 2.361   | NO        | NO          | 35%          | Reject  | Reject          |                            |
| Sb          | mg/L  | 0.006                         | N/A                 | N/A     | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Ba          | mg/L  | 2                             | 0.1                 | 0.091   | NO        | NO          | 79%          | Reject  | Reject          |                            |
| Cr          | mg/L  | 0.05                          | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cu          | mg/L  | 1                             | 0.02                | N/A     | N/A       | NO          | 75%          | Do not Reject   | Do not Reject   |                            |
| Fe          | mg/L  | 1                             | 0.1                 | 8.701   | YES       | NO          | 8%           | Do not Reject   | Do not Reject   | 8.701                      |
| Hg          | mg/L  | 0.002                         | N/A                 | N/A     | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Ag          | mg/L  | 0.05                          | 0.05                | N/A     | N/A       | N/A         | 100%         | N/A   | N/A             |                            |
| Tl          | mg/L  | 0.002                         | N/A                 | N/A     | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Zn          | mg/L  | 10                            | 0.1                 | 3.583   | NO        | NO          | 56%          | Reject  | Reject          |                            |

**Note:**

1. See Table 1 for sources of Comparison Values (CV)
2. RL is an abbreviation of reporting limit
3. Single sample hypotheses tests are not applicable to datasets having 100% censored data

**TABLE B.5**  
**Summary Statistics for COPCs and Trace Metals in Zone 3 Background Groundwater**

| Parameter   | Units | Total Data | Percent Nondetect | Minimum Detected | Maximum Detected | Mean of Detected | Median of Detected | UCL95 of Mean |
|-------------|-------|------------|-------------------|------------------|------------------|------------------|--------------------|---------------|
| Al          | mg/L  | 186        | 68.28%            | 0.1              | 1.68             | 0.422            | 0.31               | 0.231         |
| As          | mg/L  | 186        | 26.88%            | 0.001            | 1.01             | 0.121            | 0.0235             | 0.175         |
| Be          | mg/L  | 186        | 100.00%           | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cd          | mg/L  | 186        | 95.16%            | 0.01             | 0.09             | 0.02             | 0.01               | 0.0113        |
| Co          | mg/L  | 186        | 9.14%             | 0.01             | 0.53             | 0.0835           | 0.06               | 0.0877        |
| Pb          | mg/L  | 185        | 97.84%            | 0.05             | 0.08             | 0.065            | 0.065              | 0.0701        |
| Mn          | mg/L  | 186        | 0.54%             | 0.42             | 7.5              | 3.25             | 3.3                | 3.436         |
| Mo          | mg/L  | 184        | 14.13%            | 0.02             | 75               | 11.88            | 3.76               | 17.43         |
| Ni          | mg/L  | 186        | 39.25%            | 0.05             | 0.67             | 0.173            | 0.12               | 0.14          |
| Se          | mg/L  | 186        | 77.42%            | 0.001            | 0.015            | 0.0026           | 0.001              | 0.00159       |
| V           | mg/L  | 186        | 100.00%           | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cl          | mg/L  | 186        | 0%                | 15               | 66               | 31.62            | 30.85              | 32.65         |
| SO4         | mg/L  | 186        | 0%                | 1319             | 4674             | 2588             | 2651               | 2674          |
| NO3_as_N    | mg/L  | 186        | 17.20%            | 0.01             | 61               | 11.34            | 4.785              | 15.61         |
| U           | mg/L  | 186        | 1.08%             | 0.0007           | 0.38             | 0.0791           | 0.039              | 0.107         |
| Chloroform  | ug/L  | 186        | 99.46%            | 1.1              | 1.1              | N/A              | N/A                | N/A           |
| Lab_TDS     | mg/L  | 186        | 0%                | 2244             | 6930             | 4115             | 4237               | 4239          |
| Rad-226     | pCi/L | 186        | 11.83%            | 0.2              | 23.7             | 5.01             | 4.5                | 4.996         |
| Rad-228     | pCi/L | 185        | 29.19%            | 1                | 22.3             | 5.34             | 4.3                | 4.509         |
| Rad_totl    | pCi/L | 185        | 9.73%             | 0.2              | 40.9             | 9.099            | 7.9                | 10.66         |
| Th-230      | pCi/L | 186        | 89.78%            | 0.2              | 57               | 6.705            | 2.3                | 1.426         |
| Pb-210      | pCi/L | 186        | 69.35%            | 1                | 11               | 2.549            | 2                  | 1.618         |
| Gross_Alpha | pCi/L | 186        | 15.59%            | 1                | 69               | 8.191            | 5.4                | 8.217         |
| Sb          | mg/L  | 1          | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ba          | mg/L  | 36         | 94.4%             | 0.54             | 0.54             | N/A              | N/A                | N/A           |
| Cr          | mg/L  | 37         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Cu          | mg/L  | 13         | 76.9%             | 0.028            | 0.06             | 0.042            | 0.038              | 0.06          |
| Fe          | mg/L  | 23         | 39.1%             | 0.03             | 67               | 9.682            | 1.45               | 12.16         |
| Hg          | mg/L  | 4          | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Ag          | mg/L  | 29         | 100.0%            | N/A              | N/A              | N/A              | N/A                | N/A           |
| Tl          | mg/L  | 0          | N/A               | N/A              | N/A              | N/A              | N/A                | N/A           |
| Zn          | mg/L  | 31         | 19.4%             | 0.02             | 6.859            | 0.766            | 0.193              | 3.539         |



**TABLE B.6**  
**Summary Comparisons of Parameter Concentrations in Zone 3 Background Groundwater to Comparison Values**

| Parameter   | Units | Comparison Value <sup>1</sup> | Max RL <sup>2</sup> | UCL95   | UCL95>CV? | Max RL>=CV? | Percent < RL | Single Sample Hypothesis Test <sup>3</sup><br>H0: Site Median >= CV |                 | Potential Background Level |
|-------------|-------|-------------------------------|---------------------|---------|-----------|-------------|--------------|---|-----------------|----------------------------|
|             |       |                               |                     |         |           |             |              | Sign Test   | Wilcoxon Signed |                            |
| Al          | mg/L  | 5                             | 0.1                 | 0.231   | NO        | NO          | 68%          | Reject  | Reject          |                            |
| As          | mg/L  | 0.01                          | 0.001               | 0.175   | YES       | NO          | 27%          | Do Not Reject   | Do Not Reject   | 0.175                      |
| Be          | mg/L  | 0.004                         | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cd          | mg/L  | 0.005                         | 0.01                | 0.0113  | YES       | YES         | 95%          | Do Not Reject   | Reject          | 0.0113                     |
| Co          | mg/L  | 0.05                          | 0.01                | 0.0877  | YES       | NO          | 9%           | Do Not Reject   | Do Not Reject   | 0.0877                     |
| Pb          | mg/L  | 0.05                          | 0.05                | 0.0701  | YES       | YES         | 98%          | Do Not Reject   | Reject          | 0.0701                     |
| Mn          | mg/L  | 0.2                           | 0.01                | 3.436   | YES       | NO          | 1%           | Do Not Reject   | Do Not Reject   | 3.436                      |
| Mo          | mg/L  | 1                             | 0.1                 | 17.43   | YES       | NO          | 14%          | Do Not Reject   | Do Not Reject   | 17.43                      |
| Ni          | mg/L  | 0.2                           | 0.05                | 0.14    | NO        | NO          | 39%          | Reject  | Reject          |                            |
| Se          | mg/L  | 0.05                          | 0.001               | 0.00159 | NO        | NO          | 77%          | Reject  | Reject          |                            |
| V           | mg/L  | 0.1                           | 0.1                 | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Cl          | mg/L  | 250                           | N/A                 | 32.65   | NO        | N/A         | 0%           | Reject  | Reject          |                            |
| SO4         | mg/L  | 2125                          | N/A                 | 2674    | YES       | N/A         | 0%           | Do Not Reject   | Do Not Reject   | 2674                       |
| NO3 as N    | mg/L  | 30                            | 0.1                 | 15.61   | NO        | NO          | 17%          | Reject  | Reject          |                            |
| U           | mg/L  | 0.03                          | 0.0003              | 0.107   | YES       | NO          | 1%           | Do Not Reject   | Do Not Reject   | 0.107                      |
| Chloroform  | ug/L  | 80                            | 1                   | N/A     | N/A       | NO          | 99%          | Reject  | Reject          |                            |
| Lab_TDS     | mg/L  | 3170                          | N/A                 | 4239    | YES       | N/A         | 0%           | Do Not Reject   | Do Not Reject   | 4239                       |
| Rad_totl    | pCi/L | 5                             | 0.2                 | 10.66   | YES       | NO          | 10%          | Do Not Reject   | Do Not Reject   | 10.66                      |
| Th-230      | pCi/L | 5                             | 0.2                 | 1.426   | NO        | NO          | 90%          | Reject  | Reject          |                            |
| Pb-210      | pCi/L | 1                             | 1                   | 1.618   | YES       | YES         | 69%          | Do Not Reject   | Reject          | 1.618                      |
| Gross Alpha | pCi/L | 15                            | 1                   | 8.217   | NO        | NO          | 16%          | Reject  | Reject          |                            |
| Sb          | mg/L  | 0.006                         | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Ba          | mg/L  | 2                             | 0.1                 | N/A     | N/A       | NO          | 94%          | Reject  | Reject          |                            |
| Cr          | mg/L  | 0.05                          | 0.1                 | N/A     | N/A       | YES         | 100%         | Reject  | Reject          |                            |
| Cu          | mg/L  | 1                             | 0.02                | 0.06    | NO        | NO          | 77%          | Reject  | Reject          |                            |
| Fe          | mg/L  | 1                             | 0.1                 | 12.16   | YES       | NO          | 39%          | Do not Reject   | Do not Reject   | 12.16                      |
| Hg          | mg/L  | 0.002                         | 0.0002              | N/A     | N/A       | NO          | 100%         | N/A   | N/A             |                            |
| Ag          | mg/L  | 0.05                          | 0.05                | N/A     | N/A       | YES         | 100%         | N/A   | N/A             |                            |
| Tl          | mg/L  | 0.002                         | N/A                 | N/A     | N/A       | N/A         | N/A          | no data   | no data         |                            |
| Zn          | mg/L  | 10                            | 0.1                 | 3.539   | NO        | NO          | 19%          | Reject  | Reject          |                            |

**Note:**

1. See Table 1 for sources of Comparison Values (CV)
2. RL is an abbreviation of reporting limit
3. Single sample hypotheses tests are not applicable to datasets having 100% censored data

# Appendices

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## Appendix C MWH (2004) Zone 3 Cost Documentation

*Prepared for:*

**UNITED NUCLEAR CORPORATION**

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**SUPPLEMENTAL FEASIBILITY STUDY  
ZONE 3 HYDROSTRATIGRAPHIC UNIT  
CHURCH ROCK URANIUM MILL TAILING SITE**

*October 2004*

*Prepared by:*

**MWH**

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## APPENDIX C COST EVALUATION DATA

### Costing Approach

Capital cost estimates were developed for five dewatering alternatives as follows:

- Alternative 3 Tunnel
- Alternative 4 Open Pit
- Alternative 5 Enhanced Well Field
- Alternative 6 Cut-off/Containment Well
- Alternative 7 Large Diameter Hole with Radial Horizontal Collection Fan (1-3 Wells)
- Alternative 8 Directionally-drilled (horizontal) well

The following describes how each cost alternative was developed and assumptions made:

- **Alternative 3 Tunnel:** An 8 ft by 8 ft drift was assumed for construction. This size drift was used in case radial drainage holes would be installed at a later date to improve drainage to the drift. A concrete floor was assumed since it would be in use for a long period of time. A ventilation system was also assumed since there would be personnel needing access during construction and the operational life. A vertical shaft was also assessed with the associated costs for a headframe and elevator system. Costs for these options were developed by the Cowin Company and Redpath who both are specialty tunneling contractors.
- **Alternative 4 Open Pit:** This option assumed that an open pit would be developed downgradient of the existing plume and would act as a sump to collect any contamination. A conceptual pit plan was developed which estimated that approximately 500,000 cubic yards of material would have to be excavated. Costs were used from other open pit mining operations that we have been involved with on various projects. It was assumed that a 1/2 mile haul would be required to stockpile material that was excavated from the pit.
- **Alternative 5 Well Field:** This option assumed between 70 and 140 vertical dewatering wells would be installed in the location of the plume. The cost of hydraulic fracturing these wells was also included. These wells and the associated pumping and piping systems would be similar to the existing dewatering wells previously installed at the site. Extracted water would be routed to the existing evaporation system. Development costs for this option were obtained from Larry Bush of UNC who has installed the existing wells at the site.
- **Alternative 6 Cut-off/Containment Wells:** This alternative includes up to 32 wells to capture the seepage-impacted groundwater as it moves downgradient. The cost of hydraulic fracturing these wells was also included. These wells and the associated pumping and piping systems would be similar to the existing dewatering wells previously installed at the site. Extracted water would be routed to the existing evaporation system.
- **Alternative 7 Large Diameter Hole with Radial Horizontal Collection Fan (Ranney-type Well):** This option assumed that between one and three 15 foot diameter vertical shafts would be sunk to a depth of approximately 175 feet which would be at the base of the contamination plume. A total of 1,500 feet of radial drainage wells drilled out horizontally from the shafts were assumed for this project. The cost estimate for the Large Diameter Hole with Radial Collection Fan (Ranney-type Well) was developed for one installation. It was hoped that this cost could be developed with assistance from Layne Drilling, Ranney-type Well Division; however, this application is not suited to their normal installation methods (in unconsolidated sediments) and therefore they did not provide costing

information. Therefore, the cost estimate for this alternative was developed based on shaft construction costing information developed during costing of the tunnel alternative.

- Alternative 8 Directionally-drilled (horizontal) well: A directional drillhole was assumed to be drilled approximately parallel down the middle of the current plume geometry. This drillhole would be started at the surface and decline to the bottom of the plume to intercept contamination. A 4,000 foot long drillhole was estimated to be required to intercept the current plume geometry. Costs from other jobs that MWH has completed were used to determine project development costs.

| SUMMARY OF CAPITAL COSTS FOR ALTERNATIVES   |          |                 |              |                    |
|---|----------|-----------------|--------------|--------------------|
|   | Quantity | Units           | Unit Cost    | Subtotal           |
| <b>Alternative 3 Tunnel</b>                 |          |                 |              |                    |
| Item  |          |                 |              |                    |
| Decline and Drift                           | 4,000    | ft              | \$800        | \$3,200,000        |
| Steel Sets                                  | 1        | ls              | \$500,000    | \$500,000          |
| Gunnite                                     | 1        | ls              | \$300,000    | \$300,000          |
| Fan System                                  | 1        | ls              | \$110,000    | \$110,000          |
| Concrete Floor                              | 4,000    | ft              | \$350        | \$1,400,000        |
| Procure and Install Dewatering Pumps        | 3        | each            | \$5,000.00   | \$15,000           |
| Engineering (10% of Direct Cost)            |          |                 |              | \$552,500          |
| CQA (5% of Direct Cost)                     |          |                 |              | \$276,250          |
|   |          |                 | <i>Total</i> | <i>\$6,353,750</i> |
| <b>Alternative 4 Open Pit</b>               |          |                 |              |                    |
| Item  | Quantity | Units           | Unit Cost    | Subtotal           |
| Excavate and Load Material                  | 500,000  | yd <sup>3</sup> | \$2.20       | \$1,100,000        |
| Haul Material ½ mile and Dump               | 500,000  | yd <sup>3</sup> | \$0.40       | \$200,000          |
| Doze Dumped Material                        | 500,000  | yd <sup>3</sup> | \$0.20       | \$100,000          |
| Procure and Install Dewatering Pumps        | 3        | each            | \$5,000.00   | \$15,000           |
| Revegetate Waste Stockpile                  | 28,000   | yd <sup>2</sup> | \$ 0.60      | \$16,800           |
| Mob/Demob (20% of Direct Cost)              |          |                 |              | \$286,360          |
| Engineering (10% of Direct Cost)            |          |                 |              | \$143,180          |
| CQA (5% of Direct Cost)                     |          |                 |              | \$71,590           |
| Contractor OH&P (30% of Direct Cost)        |          |                 |              | \$429,540          |
|   |          |                 | <i>Total</i> | <i>\$2,362,470</i> |
| <b>Alternative 5 Well Field (70 Wells)</b>  |          |                 |              |                    |
| Item  | Quantity | Units           | Unit Cost    | Subtotal           |
| Extraction Wells with Pumps                 | 70       | ea              | \$6,300      | \$441,000          |
| Hydraulic Fracturing of Extraction Wells    | 70       | ea              | \$12,000     | \$840,000          |
| Extraction Wells (with Pumps) in Alluvium   | 15       | ea              | \$6,300      | \$94,500           |
| Collection System                           | 1        | ea              | \$50,000     | \$50,000           |
| Engineering (10% of Direct Cost)            |          |                 |              | \$58,550           |
|   |          |                 | <i>Total</i> | <i>\$1,484,050</i> |
| <b>Alternative 5 Well Field (140 Wells)</b> |          |                 |              |                    |
| Item  | Quantity | Units           | Unit Cost    | Subtotal           |
| Extraction Wells with Pumps                 | 140      | ea              | \$6,300      | \$882,000          |
| Hydraulic Fracturing of Extraction Wells    | 140      | ea              | \$12,000     | \$1,680,000        |
| Extraction Wells (with Pumps) in Alluvium   | 15       | ea              | \$6,300      | \$94,500           |
| Collection System                           | 1        | ea              | \$75,000     | \$75,000           |
| Engineering (10% of Direct Cost)            |          |                 |              | \$58,550           |
|   |          |                 | <i>Total</i> | <i>\$2,790,050</i> |

| SUMMARY OF CAPITAL COSTS FOR ALTERNATIVES   |          |       |              |                    |
|---|----------|-------|--------------|--------------------|
|   | Quantity | Units | Unit Cost    | Subtotal           |
| <b>Alternative 6 Cut-off/Containment Wells</b>  |          |       |              |                    |
| Item  | Quantity | Units | Unit Cost    | Subtotal           |
| Extraction Wells with Pumps   | 32       | ea    | \$6,300      | \$201,600          |
| Hydraulic Fracturing  | 32       | ea    | \$12,000     | \$384,000          |
| Collection System   | 1        | ea    | \$50,000     | \$50,000           |
| Engineering (10% of Direct Cost)  |          |       |              | \$58,550           |
|   |          |       | <i>Total</i> | <i>\$694,150</i>   |
| <b>Alternative 7 Large Diameter Hole with Radial Horizontal Collection Fan<br/>(One Ranney-type Well)</b> |          |       |              |                    |
| Item  | Quantity | Units | Unit Cost    | Subtotal           |
| Shaft Excavation  | 175      | ft    | \$1,200      | \$210,000          |
| Headframe   | 1        | ea    | \$1,500,000  | \$1,500,000        |
| Radial Drillholes   | 1500     | ft    | \$30         | \$45,000           |
| Procure and Install Pump  | 1        | each  | \$10,000.00  | \$10,000           |
| Engineering (10% of Direct Cost)  |          |       |              | \$176,500          |
| CQA (5% of Direct Cost)   |          |       |              | \$88,250           |
|   |          |       | <i>Total</i> | <i>\$2,029,750</i> |
| <b>Alternative 8 Directionally-drilled (horizontal) well</b>  |          |       |              |                    |
| Item  | Quantity | Units | Unit Cost    | Subtotal           |
| Directional Drilling  | 4,000    | ft    | \$300.00     | \$1,200,000        |
| Procure and Install Pump  | 3        | each  | \$5,000.00   | \$15,000           |
| Mob/Demob (20% of Direct Cost)  |          |       |              | \$243,000          |
| Engineering (10% of Direct Cost)  |          |       |              | \$121,500          |
| CQA (5% of Direct Cost)   |          |       |              | \$60,750           |
| Contractor OH&P (30% of Direct Cost)  |          |       |              | \$364,500          |
|   |          |       | <i>Total</i> | <i>\$2,004,750</i> |
| <i>(Unit Rates Include Other Indirect Costs)</i>  |          |       |              |                    |