APPENDIX M

Aquifer Exemption Boundary Justification

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Technical Memorandum

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From: Hal Demuth

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Subject: Calculation Of The Proposed Aquifer Exemption Distance Beyond The Monitor Ring: Dewey Burdock ISR Uranium Project, South Dakota

A science-based calculation has been prepared to establish a reasonable distance beyond the monitor ring that the Production Zone Aquifer (Inyan Kara including the Fall River and Chilson) should be exempted at the Dewey Burdock Project in Custer and Fall River Counties, South Dakota. The aquifer exemption, including additional distance outside of the monitor well ring, is necessary for Powertech to recover uranium using insitu recovery mining methods while remaining protective of underground sources of drinking water (USDWs).

Based on the recent meetings held with the US Environmental Protection Agency Region 8 (USEPA), Powertech and Petrotek Engineering Corporation (PEC) it was agreed that the exempted aquifer should include some distance beyond the monitor well ring. It was further agreed that the general approach would be similar to that recently approved by EPA for the Ur Energy Lost Creek Project in Wyoming.

A scientific calculation of the aquifer exemption distance past the monitor well ring has been prepared that includes several components. One component involves a simple trigonometric calculation of the distance that a potential excursion could extend beyond a monitor ring outline before being detected at a monitor ring well (assuming radial flow). This factor is referred to as ΔT. The second component involves the distance that the excursion can travel from the time of initial detection to the time that recovery operations are implemented (indicated as Δd). The final component is a dispersivity factor (DF) that is applied to account for heterogeneity in the subsurface that potentially can result in movement of an excursion beyond the distances calculated using assumptions of a homogenous isotropic aquifer system. The combination of these components represents the distance beyond the monitor well ring boundary that should be included in the exempted aquifer (AE_b) as represented by

$$AE_b = \Delta T + \Delta d + DF.$$

The calculation of each of these terms is provided below. Other factors, such as diffusion and attenuation were considered but were not included in the calculation as described later in this document.

The trigonometric component (ΔT) of the calculation is represented in Figure 1 and defined as follows. Trigonometry is used to calculate the maximum distance that an excursion could have traveled outside of the monitor ring boundary by the time the excursion is first detected at a monitor ring well. Key assumptions in the trigonometric calculation are that the aquifer is homogenous and isotropic (i.e., has uniform aquifer properties in the lateral and vertical directions), that there is radial flow from a point source (a well) and that the discharge rate and the hydraulic gradient remain constant from the time the excursion reaches the monitor ring boundary to the time it is actually detected at a monitor ring well (Figure 1).

The maximum distance that the excursion could travel outside the monitor ring outline before being detected by a monitor ring well (under the assumptions previously described) would occur under a scenario where the injection well responsible for the excursion is positioned midway between two monitor ring wells (Figure 1). The monitor ring at the Dewey Burdock Project is placed at a distance of 400 feet from the outer edge of the wellfield and the spacing between monitor ring wells is 400 feet. As shown on the figure, the distance from the injection well to the monitor ring boundary is 400 feet. A hypothetical excursion could reach the monitor ring boundary before being detected at a monitor ring well. Assuming radial flow from the injection well responsible for the excursion, the maximum distance beyond the monitor ring that the hypothetical excursion could travel before being detected would be approximately 47 feet. Although this calculation is the maximum distance under the prescribed assumptions, the calculation does not account for any dispersion or preferential flowpaths that may occur as a result of aquifer heterogeneity.

The second component in the calculation is the distance of excursion migration between initial detection and implementation of excursion recovery (Δd). Numerical modeling has previously been used to evaluate excursion recovery for the project area. For the model simulations, it was assumed that the time between excursion detection and implementation of corrective action was 30 days, and verification and corrective action would require an additional 45 days (e.g., a total of 75 days). The distance traveled during the 75 day period is a function of the groundwater velocity during the time of the excursion and the groundwater velocity is directly proportional to the hydraulic gradient. Average interstitial groundwater velocity (v in ft/d) is calculated using the Darcy equation as:

$$v = (ki)/\phi$$

where:

k = hydraulic conductivity in (ft/d),
i = hydraulic gradient (ft/ft), and
ϕ = porosity (unitless).

Based on site pump testing data, the k value used in the model was 4.0 ft/d and the value for ϕ was 0.25. The hypothetical excursions were simulated as an out of balance situation within the wellfield with the extraction rate in one of the outer well patterns reduced to 25 percent of the typical rate for the wellfield. In the model simulations, the maximum hydraulic gradient away from the wellfield in the vicinity of the monitor ring affected by the excursion was 0.02 ft/ft. In comparison, the background hydraulic gradient (under nonpumping conditions) is considerably lower at 0.005 ft/ft (a factor of 4 lower). The simulated excursions traveled a maximum distance of 24 feet during the 75-day period from detection to confirmation of beneficial corrective action.

Combination of ΔT and Δd results in a distance of 71 feet from the monitor ring boundary. The calculated boundary is shown on Figure 2. However, as previously noted the trigonometric method assumes radial flow in a homogenous, isotropic aquifer system and does not account for the variability that is inherent in typical uranium roll front deposits that are commonly present in fluvial deposited systems. The numerical modeling of excursion detection and recovery addresses limited variability in aquifer properties and operational conditions that resulted in the hypothetical excursion. Because of the variability and uncertainty in subsurface conditions, primarily as they relate to aquifer properties, it is proposed that a dispersivity factor (DF) be applied to the science based calculation.

Dispersion is the process whereby some of the water molecules and solute molecules travel more rapidly than the average linear velocity and some travel more slowly. Dispersion accounts for variability in solute transport due to aquifer heterogeneity on both a micro-scale and a macro-scale. At the micro-scale, the solutes are spread through mechanical dispersion via velocity variability within pore channels, differences in pore size and tortuousity of pore channels (Freeze and Cherry 1979). At a slightly larger scale, heterogeneities within the aquifer matrix (such as variability in grain size, clay content etc) cause permeability differences that result in flow fields with varying velocities (Spitz and Moreno 1994). At the field scale, geologic features, such as sedimentary facies (channel sands, overbank deposits, etc) can result in preferential movement of solutes at higher or lower than average groundwater velocities, in resulting additional dispersion.

Prediction of dispersive spreading requires that travel-distance dependent dispersion coefficients be introduced (Naff, 1984). Published data summarized in Spitz and Moreno (1994) suggests that a representative estimate of longitudinal dispersivity (along the primary flow direction) is about 10 percent of the travel distance. That estimate is based on the results of over 80 reported studies of dispersivity in a variety of lithologies (most of which were predominately sand, silts and gravels). The calculated impact of dispersion considered herein is $(400 + 47 + 24) * 0.1 = 47$ feet.

Other factors that could influence the movement of an excursion beyond a monitor ring include diffusion and attenuation. Diffusion is the movement of a solute from a zone of higher concentration to a zone of lower concentration. Diffusion is independent of any bulk movement of the solution and is driven by a concentration gradient. In groundwater systems, diffusion is a relatively slow transport process and for time frames associated with uranium insitu recovery operations (days to several years) is generally considered negligible. For purposes of this demonstration, any additional migration of an excursion that might be the result of diffusion is negligible and therefore disregarded.

Attenuation includes a number of processes that could limit the rate or distance that an excursion moves beyond the monitor well ring. Among these are adsorption/desorption, complexation, precipitation/dissolution, oxidation/reduction, hydrolysis, and decay (radioactive or biologic). The effects of these processes vary for each solute and can be interdependent on the subsurface environment of the aquifer system and may include factors such as redox condition, availability of sorption sites, general chemistry of the groundwater, etc. The mobility of certain solutes, such as uranium, can be particularly sensitive to redox conditions and may be substantially attenuated along a groundwater flowpath.

However, one of the indicator parameters used to identify the occurrence of an excursion is chloride. Chloride is a conservative (non-reactive) solute that is not significantly attenuated (other than through dilution) during groundwater transport. The distance that chloride (and therefore the excursion) moves outside the monitor ring should be minimally affected by attenuation processes. Further, the purpose of this calculation is to estimate the distance beyond the monitor ring that an excursion could potentially travel prior to commencement of recovery operations. Omitting consideration of attenuating processes for purposes of this calculation provides a better estimate of the maximum distance that the excursion could travel and is more protective of underground sources of drinking water (USDWs).

The resulting distance beyond the monitor ring boundary to be included in the exempted aquifer is calculated as follows;

$AE_b = \Delta T + \Delta d + DF = 47 \text{ ft} + 24 \text{ ft} + 0.1(400 \text{ ft} + 47 \text{ ft} + 24 \text{ ft}) = 118 \text{ feet}$

The total aquifer exemption boundary distance from the edge of the wellfield, and including dispersion, is 400 + 47 + 24 + 47 = 518 feet.

The science-based calculation of 118 feet is rounded to 120 feet for ease of surveying and plotting on maps. A distance of 120 feet provides a reasonable extension beyond the monitor ring boundary to conduct uranium recovery using insitu mining methods while remaining protective of USDWs. This proposed aquifer exemption boundary is also shown on Figure 2.

It is noted that this calculation method is simplistic and useful for defining the initial reclassification/exemption area. However, as the project develops, and especially as concurrent production and restoration operations are conducted, it may be necessary to slightly modify the calculation methodology based on additional site data.

References

R. Freeze and J. Cherry 1979. Groundwater. Prentice Hall Inc. New Jersey

Naff. R. 1984. Definition of Global Dispersion Coefficients. Bericht PSE-No. 83/4B Projekt Sicherheitstuden Entosorgung. TU Berlin. Hahn-Meitner-Institut.

Spitz, K. and J. Moreno. 1996. A Practical Guide to Groundwater and Solute Transport Modeling. John Wiley & Sons, Inc. New York.

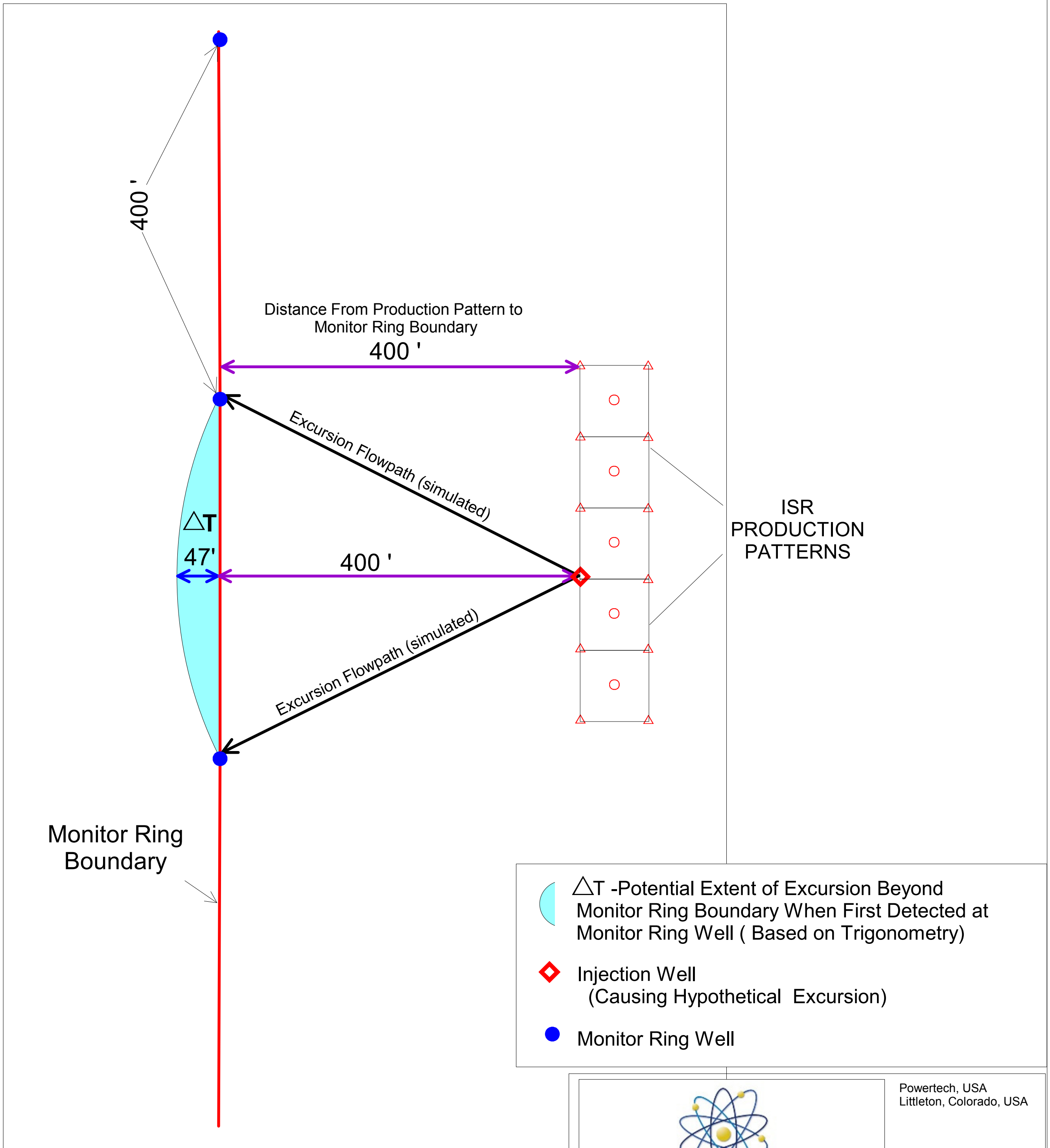

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FIGURE 1
Trigonometric Method for Calculating Excursion Travel Distance Beyond Monitor Ring (△T)

Dewey-Burdock Permit Area

Issued For: U.S. EPA — Drawn By: AAP
Issued/Revised: 9.13.11
Drawing No.: Figure 1_DBAE
0 200 400 feet

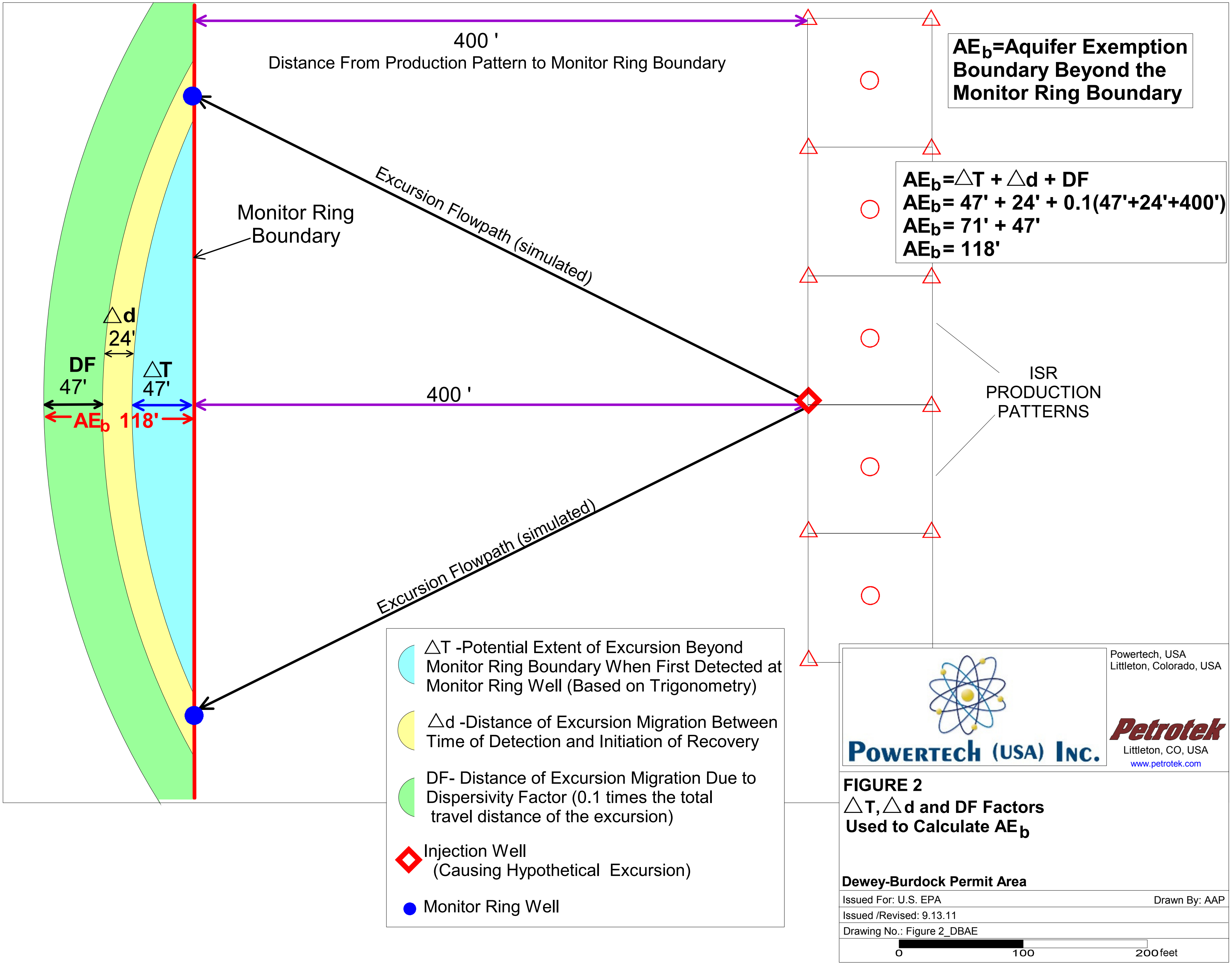
400 '
Distance From Production Pattern to Monitor Ring Boundary
AEb=Aquifer Exemption Boundary Beyond the Monitor Ring Boundary
AEb=△T + △d + DF
AEb= 47' + 24' + 0.1(47'+24'+400')
AEb= 71' + 47'
AEb= 118'
Monitor Ring Boundary
Excursion Flowpath (simulated)
△d
24'
DF
47'
△T
47'
AEb 118'
400 '
ISR PRODUCTION PATTERNS
Excursion Flowpath (simulated)
△T -Potential Extent of Excursion Beyond Monitor Ring Boundary When First Detected at Monitor Ring Well (Based on Trigonometry)
△d -Distance of Excursion Migration Between Time of Detection and Initiation of Recovery
DF- Distance of Excursion Migration Due to Dispersivity Factor (0.1 times the total travel distance of the excursion)
Injection Well (Causing Hypothetical Excursion)
Monitor Ring Well
Powertech, USA
Littleton, Colorado, USA
POWERTECH (USA) INC.
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FIGURE 2
△T, △d and DF Factors Used to Calculate AEb
Dewey-Burdock Permit Area
Issued For: U.S. EPA
Drawn By: AAP
Issued /Revised: 9.13.11
Drawing No.: Figure 2_DBAE
0
100
200 feet