TECHNICAL MEMORANDUM 4

ADDENDUM TO
FINAL PHASE III RFI/RI WORK PLAN
TRACER TEST PLAN
881 HILLSIDE AREA
(OPERABLE UNIT NO. 1)

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS PLANT
GOLDEN, COLORADO

ENVIRONMENTAL RESTORATION PROGRAM

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1.0 PURPOSE AND SCOPE

This technical memorandum describes techniques that are specific to the tracer tests described in the Final Phase III RFI/RI Work Plan, Revision 1, March 1991 (Work Plan) for the 881 Hillside Area, Operable Unit 1 (OU1) at the Rocky Flats Plant (RFP). The addendum is compatible with and complementary to Environmental Management Department (EMD) Groundwater Standard Operating Procedure (SOP) Tracer Tests GW 2.07, Revision 0, dated October 29, 1991, and is intended to extend the general procedures described in that SOP to cover OU1-specific test requirements and modifications necessary to implement the scope of work described in the Work Plan.

The Work Plan proposes that three multi-well tracer tests be performed in the Woman Creek alluvium. The Work Plan suggests that distilled water be used as a tracer in the *in situ* tracer tests, but allows for the use of an alternative, rhodamine WT dye, if this is found to be more appropriate. In consideration of the possibility that both of the proposed tracers may not be sufficiently conservative or detectable, the scope of work has been modified to include the assessment of distilled water, rhodamine WT dye, and potassium bromide as potential tracers in a tracer evaluation test. The results of the evaluation test will be used to select the most appropriate tracer for use. This technical memorandum describes equipment and procedures required for both the tracer evaluation test and the multi-well tracer tests.

2.0 EQUIPMENT AND MATERIALS

2.1 EQUIPMENT FOR TRACER EVALUATION TEST

Following wellpoint development and sampling, the tracer evaluation test will be conducted at a single wellpoint to assess the appropriateness of three different tracers for use in the multi-well tracer tests. The tracers to be evaluated are distilled water, rhodamine WT dye, and potassium bromide. Rhodamine WT dye and potassium bromide have been selected for these tests because of their conservative behavior, absence in the hydrogeologic environment, and ease of detection in aqueous samples. The results from *in situ* testing of each tracer will be

analyzed and the most effective tracer, in terms of its conservative nature and applicability, will then be selected for use in the multi-well tests.

2.1.1 Gradient Control and Sampling Equipment

The following is a general list of equipment needed to perform the *in situ* tracer tests:

- Reliable power source (5kw generator or equivalent)
- Polyethylene reservoir tank with sufficient volume to hold up to 30 gallons of tracer solution
- Tracer solution mixing equipment
- The selected tracer(s) including potassium bromide (2.5 kg) and rhodamine WT (100 g)
- Equipment to regulate the flow of tracer solution into the aquifer via the tracer injection/recovery well
- Flow meter or other means to measure the rate of solution inflow into the injection well
- Peristaltic sampling pump with a capacity range appropriate for the hydrologic conditions such as a Geotek 350 RPM variable speed pump or equivalent
- Automatic fraction collector with time-based and drop-based collection modes such as the Eldex universal fraction collector or equivalent
- Sample bottles or test tubes (to fit the fraction collector)
- Perforated 1/2-inch-diameter downhole teflon injection tube for tracer injection
- Five psi pressure transducer with an accuracy of $\pm$ 0.14 inch
- Data logger
- Electronic water level indicator graduated in hundredths of a foot
- Stop watch or clock readable to 1-second increments
- Wastewater storage tank or waste drums for excess produced and development water

- Adequate 1.5-inch-diameter stainless steel drive points, each having a sufficient length of well screen to fully penetrate the saturated thickness of the aquifer. Well screen length and slot size will be determined from site-specific hydrogeologic information obtained from drilling the exploratory borings in addition to wells previously installed nearby; 1.5-inch-diameter carbon steel blank casing for use in completion of the well point from the top of the well screen to 1 foot above the ground surface.

- Equipment and supplies for the drilling and development of the test well consistent with procedures described in groundwater SOP GW 2.08.

- Field notebook

- Field data sheets.

2.1.2 Field Tracer Analysis Equipment

The following is a general list of equipment and supplies needed to perform the tracer evaluation test for bromide:

- Portable field pH/ion-specific electrode meter

- Bromide ion-specific electrode

- Sodium nitrate (5 M $NaNO_3$) ionic strength adjustment solution (475 ml)

- Single-junction electrode internal filling solution

- Bromide (0.1 M KBr) activity calibration standard(s) (475 ml)

- Adaptor for standard electrode to BNC meter (optional)

- Reagent grade potassium bromide (KBr) (2.5 kg)

- Test tubes, sample bottles, or beakers

- Thermometer calibrated to $\pm$ 0.1°C full scale.

The following is a general list of equipment and supplies needed to perform the tracer evaluation test for rhodamine WT dye:

- Portable field fluorometer or spectrometer with a photomultiplier wavelength range of 254-650 nM such as the Turner Model 112 Digital fluorometer or equialent

- Calibration standard(s)
- Reagent grade rhodamine WT dye (100g)
- Test tubes, sample bottles, or beakers
- Thermometer calibrated to $\pm$ 0.1° full scale.

The following is a general list of equipment and supplies needed to perform the tracer evaluation test for distilled water:

- Portable field conductivity meter with temperature compensation capability
- Calibration standard(s)
- Distilled water (900 gallons)
- Flow-through conductivity cell and probe
- Test tubes, sample bottles, or beakers.

2.2 EQUIPMENT FOR MULTI-WELL TRACER TESTS

2.2.1 Gradient Control and Sampling Equipment

The equipment required for multi-well tracer tests includes all equipment listed in Section 2.1.1 for the single well tracer evaluation test with the following additions:

- Fourteen (15 total) 5 psi pressure transducers with an accuracy of $\pm$ 0.14 inch
- One or more data logger capable of recording 15 channels simultaneously
- Equipment to regulate flow of tracer solution into the five injection wells
- Four (5 total) perforated 1/2-inch-diameter downhole injection tubes for tracer injection
- Six (7 total) peristaltic sampling pumps

- Four (5 total) fraction collectors
- Four (5 total) flow meters or calibrated glassware to measure the rate of tracer solution inflow into injection wells.

2.2.2 Tracer Detection and Monitoring Equipment

The equipment required for detection and monitoring of the tracer during the multi-well tests will depend on the specific tracer that is selected from the results of the evaluation test. Equipment requirements for the three potential tracers are listed below:

- Bromide tracer:
  - Equipment listed in Section 2.1.2
    - Backup reference and ion-specific electrodes in addition to the ones listed

- Rhodamine WT dye tracer:
  - Equipment listed in Section 2.1.2

- Distilled water tracer:
- Equipment listed in Section 2.1.2
- Four (5 total) flow-through conductivity cells and probes.

3.0 PROCEDURES

3.1 TRACER EVALUATION TEST PROCEDURES

3.1.1 Test Well Installation, Completion, and Development

Based on the results of the exploratory borings drilled at each of the three test sites, one test location will be selected as a representative site for the tracer evaluation test. An approximate 8-inch-diameter borehole will be advanced using continuous flight hollow-stem augers to within one foot of the observed groundwater elevation at that location following procedures described in SOP GT.02. The well materials will consist of 1.5-inch-diameter stainless steel well screen of a length that is 1 foot greater than the estimated saturated aquifer thickness for that location. The well screen slot size will be determiend using the results of a

sieve analyses on aquifer meterials collected from the exploratory boring. A steel or stainless steel drive point will be affixed to the bottom of the screen to allow the well to be pushed or driven into place through the saturated aquifer materials. The remainder of the well will consist of 1.5-inch-diameter carbon steel blank casing from the top of the well screen to 1 foot above the ground surface. The wellpoint will be inserted to the bottom of the borehole through the augers. The wellpoint will be driven to a depth such that the base of the well screen is at the bottom of the saturated aquifer. The annulus space remaining around the blank well will consist of natural formation materials which will fill the annulus upon auger retrieval.

The well will be developed using methods described in SOP GW 2.08, or equivalent methods. Immediately after well development has been completed (including the removal of five casing volumes of groundwater), a water quality sample will be collected using methods described in SOP GW.06. This water sample will be analyzed in a laboratory for common ion chemistry (sodium, calcium, iron, silicon, aluminum, potassium, magnesium, manganese, bicarbonate, nitrate, sulfate, fluoride, chloride, bromide), total organic carbon, and total dissolved solids. Electrical conductivity and pH will be determined in the field. In addition, potassium bromide standards will be prepared and sent for confirmatory laboratory analysis prior to being used to develop a bromide calibration curve for analysis of bromide tracer test breakthrough data.

After the tracer evaluation test is complete, the wellpoint will be withdrawn from the ground and the remaining borehole will be grouted throughout its length according to SOP GT.05.

3.1.2 Equipment Installation and Instrumentation

Following the installation and development of the test well, the aquifer will be allowed to return to its prior hydrostatic conditions. A pressure transducer will be lowered to the bottom of the well screen and attached to a data logger to record groundwater levels to the nearest

0.01 foot and to confirm that equilibrium has been achieved. Water levels will be recorded both before and during the test.

The tracer reservoir and mixing equipment will be situated within several feet of the injection well and the injection tube will be inserted into the well so that the perforations are all within the screened interval. The injection tube will be connected to the reservoir via the supply line, which shall include an inline flow meter, flow regulation equipment, and a hand-operated valve.

For the withdrawal or tracer recovery portion of the test, the peristaltic sampling pump and fraction collector shall be available, as well as sample collection bottles or test tubes. All other test equipment listed in Sections 2.1.1 and 2.1.2 shall be available, appropriate to the nature of the tracer being tested.

3.1.3 Tracer Preparation

Based on the aquifer hydraulic properties as presented in the Work Plan, a total tracer solution injection volume of 30 gallons for each tracer tested should be adequate for the tracer evaluation test. The concentration of each tracer solution should be no less than two orders-of-magnitude greater than the estimated detection limit for the tracer as determined by the appropriate field tracer analysis method. For the distilled water tracer, pure distilled water will be used. The tracer in the reservoir will be thoroughly mixed by an electric stirring device before and during the test to ensure a uniform concentration.

3.1.4 Test Procedures

Before tracer solutions are introduced into the well, a series of short, constant-rate injection and withdrawal step-tests shall be conducted to evaluate the performance of the well and to help select optimum injection and withdrawal rates for the tracer test. The general procedure for a step-drawdown test (withdrawal) is described in SOP GW 2.08. Depending on site conditions, the lowest pumping rate should be 0.05 gpm or lower to ensure a sustainable flow

rate. After the step-drawdown test is complete and equilibrium conditions return, a step-injection test will be conducted by introducing potable water to the aquifer using the same flow-rate steps used in the step-drawdown test. The sustainable flow rate that will be selected from the results is one that will produce no significant change in saturated aquifer thickness (less that $\pm$ 10 percent) during the tracer test.

Tracer solution will be introduced into the well at a constant rate so that a significant rise in the water table (more than 10 percent of initial saturated aquifer thickness) will not occur. The injection will continue until the tracer solution reservoir is depleted. The flow rate, time, and water level will be recorded continuously or very frequently during the injection portion of the test by the pressure transducers to assure sufficient data are collected throughout for adequate analysis.

After the injection is complete, the intake of the peristaltic pump will be inserted into the well at an appropriate depth below the water table, and the well will be pumped at a rate equal to that of the injection. The well will be pumped at that rate until a volume of groundwater is removed that is twice the volume of injected tracer solution. During this period, the fraction collector will be used to collect samples of the recovered groundwater at defined regular and frequent intervals (30-second to 10-minute intervals) so that a minimum of 60 samples are collected during recovery.

After the recovery portion of the test has been completed, all equipment that was in contact with the tracer solution or groundwater will be decontaminated according to SOP FO.03. The groundwater level will be allowed to reach approximate equilibrium and the equipment will be redeployed. A second tracer solution will then be prepared and that tracer will be injected and recovered following the same procedures. These procedures will be repeated again for the third tracer to complete the tracer evaluation test.

The three tracers will be tested in the following order: 1) distilled water; 2) potassium bromide solution; and 3) rhodamine WT dye. If adequate information on material or trace dispersion in this aquifer is obtained during any stage of this test, the other planned tests may not be conducted. This sequence is expected to cause the least amount of interference among the three tracers tested. Samples collected by the fraction collector will be analyzed in the field upon collection to determine whether tracer breakthrough has occurred. The results will be plotted graphically to better understand the rate of change in tracer concentrations with time. Samples will be analyzed using the field analysis methods appropriate for each tracer as specified by the manufacturer, accepted scientific methodology and according to procedures described in the instrument instruction manuals.

Prior to the start of sample analysis, each instrument will be calibrated using commercially available stock standards and/or appropriate dilutions of traceable stock standards. The manufacturer's instructions will be followed for instrument calibration and use. The calibration results will be recorded in the field notebook. In the case of the bromide analyses, ion-specific electrode readings will be quantified using the bromide calibration curve developed during calibration and confirmed by laboratory analysis prior to the startup of the tracer test. A three-point calibration curve reflecting the range of bromide concentrations expected in the tracer samples will be used at a minimum. When rhodamine WT dye is used as a potential tracer, the fluorometer or spectrometer will be calibrated for the emission wavelength characteristic of the dye. Concentrations of the dye will be obtained from sample fluorescence readings quantified using the rhodamine WT calibration curve. When distilled water is used as a potential tracer, the specific conductance of tracer samples will be analyzed using a conductivity meter. Field specific conductance measurement procedures using a HACH Conductivity/TDS Meter (model 44600) are described in SOP GW.05. If an instrument other than the HACH meter is used, the manufacturer's instructions will be followed for calibration and analysis.

3.1.5 Data Interpretation

The results of the tracer evaluation tests for each of the tracers will be reduced and evaluated to select the most appropriate and detectable tracer for use in the multi-well tracer tests. Test results will be interpreted using the methods described in the references listed in GW 2.07 so that the most conservative and readily detected tracer can be selected for site conditions.

3.2 MULTI-WELL TRACER TEST PROCEDURES

The multi-well tracer tests will be conducted using the same 15-wellpoint array in which the multi-well pumping tests are conducted at each of the three test locations in the Woman Creek alluvium. The multi-well tracer tests will be performed as soon as possible after the pumping tests have been completed. In general, this should be possible as soon as groundwater levels return to their hydrostatic conditions. Following the completion of each tracer test, the 15-wellpoint array will be destroyed by extracting the wellpoints for reuse at the next multi-well array location.

The 15 wells will be arranged in a three-well by five-well array, with the long axis (five wells per row) oriented perpendicular to the direction of groundwater flow. In this arrangement, the five upgradient wells on one side of the array will be selected to serve as injection wells for the introduction of tracer into the aquifer. The five wells on the downgradient side of the array will serve as pumping or tracer recovery wells and the central row of five wells will serve as observation wells.

3.2.1 Equipment Installation and Instrumentation

The five upgradient wells will be instrumented as tracer solution injection wells, the middle row of five wells as observation wells, and the downgradient row of five wells as extraction wells. The tracer test will be conducted as a constant hydraulic gradient test with the continuous introduction of constant concentration tracer at the injection wells and the constant removal of groundwater at the extraction wells. Groundwater samples will only be collected

at the middle well of the injection well row, at the middle well of the middle well row, and at the three middle wells of the extraction well row (Figure 5-2 in the Work Plan).

All wells in the wellpoint array will be instrumented with a pressure transducer for water level measurement. The transducers will be connected to a multichannel data logger for recording of water levels before and during the tracer test. This information will be used to record test conditions and to determine any significant fluctuations in hydraulic gradient that may affect the test. It is likely that this transducer network will be in place following the multi-well pumping test.

The five injection wells will be equipped for injection of tracer through perforated injection tubes leading from the tracer solution reservoir via a distribution manifold. The line to each well will include an inline flow rate meter, a flow regulating device, and a manual valve to cut off flow. Each inline flow regulator will adjust flow so as to maintain a constant hydraulic head in the associated well. The inflow line from the tracer solution reservoir to the manifold will contain a manually operated valve to control or shut off flow.

The five down gradient extraction wells will each be equipped with an extraction peristaltic pump to maintain a constant drawdown condition in the associated well. Flow meters or other measurement devices will be installed to measure the rate of extraction from each well. Extracted water will be pumped to a wastewater storage reservoir or to waste drums for later handling.

A total of five fraction collectors will be used to collect water samples from the five wells designated for sampling. The wells that will be sampled are the middle well of the injection well row, the middle well of the middle or observation well row, and the three middle wells of the extraction well row. This pattern has been selected since it is believed that the major direction of dispersion will be parallel to the injector well. The middle injection well and the middle observation well will be equipped with peristaltic sampling pumps to supply the

fraction collectors for those wells. The three extraction wells to be sampled will already be equipped with peristaltic pumps because they are extraction wells. These pumps can be used to supply their corresponding fraction collectors. While the middle extraction well is expected to provide the most useful breakthrough data, the adjacent extraction wells will also be sampled to provide supplementary breakthrough information in case unusual conditions are encountered.

Water pumped from the aquifer during the multi-well pumping test will be stored on site in a tank for reuse during the preliminary portion of the tracer test. The water will be used to establish near steady-state hydrostatic conditions within $\pm$ 20 percent of original before tracer solution is injected into the aquifer.

3.2.2 Tracer Preparation

Based on the aquifer hydraulic properties presented in the Work Plan, a total tracer solution injection volume of 200 gallons should be adequate for each tracer test. However, the results of the multi-well pumping test shall be analyzed and the tracer volume reassessed based on the updated hydraulic properties before the tracer test is undertaken. The concentration of the selected tracer will be no less than two orders of magnitude greater than the estimated detection limit for the tracer as determined by the appropriate field tracer analysis method. The tracer solution in the reservoir will be mixed thoroughly by an electric stirring device before and during the test to ensure a uniform tracer concentration.

3.2.3 Test Procedures

Groundwater extracted and stored during the multi-well pumping test will be injected into the five injection wells so that the hydraulic head within each well is held constant at a level of 1 foot higher than the static water table ensuring that fluctuations in elevation are no more than $\pm$ 0.2 foot. The extraction wells will be pumped at a rate that will maintain groundwater elevations in each well at approximately static water levels (also $\pm$ 0.2 foot). When an approximate steady-state condition has been established, tracer solution will be introduced at a

constant rate at the five injection wells. The tracer will be injected continuously until breakthrough has been observed at the extraction wells. Breakthrough is estimated to occur in less than 20 hours under these conditions (see Work Plan).

The five sampled wells should be sampled at regular and frequent intervals (2- to 15-minute intervals) using pre-programmed sample fraction collectors. A minimum of 100 samples will be collected from each of the five sampled wells during the course of the test. The samples should be analyzed on a regular basis (every 2 to 4 hours) using the appropriate field analysis method to ascertain when breakthrough of the tracer has occurred. Samples will be analyzed using the field analysis instrument appropriate to the selected tracer and according to procedures described in the instrument instruction manual. All instruments will be calibrated according to the manufacturer's specifications and as briefly described in Section 4.1.4. The fraction collectors will be adjusted to collect the smallest reasonable sample upon which to perform field tracer analysis. Sampling will not remove sufficient groundwater volume to cause a significant deflection of groundwater flow around any sampled well. This will be monitored by continually evaluating the water levels in the surrounding wells to determine if decreases in water level occur during sampling.

Water level data will be collected and monitored frequently throughout the duration of the test. The water levels will be confirmed regularly by manual water level readings taken using electronic water level indicators. These data, as well as other pertinent information such as precipitation, will be logged regularly.

The tracer test can be terminated when 80 to 90 percent of the relative concentration of injected tracer has been recovered. It should be noted that due to the configuration of the wellpoint array and the location of the injection wells relative to the extraction wells, a portion of the injected tracer may not be recoverable. Therefore, professional judgement may have to be exercised as well as EG&G approval to determine the appropriate end to the test.

All groundwater produced during the test should be stored in a tank or in drums for later disposal as described in SOP FO.05. All equipment used should be discarded if disposable or decontaminated according to SOP FO.03.

After extraction and decontamination, the wellpoints used to form the wellpoint array will be extracted from the ground for possible reuse in the next multi-well pumping test and tracer test array. The remaining boreholes should be plugged with grout according to SOP GT.05.

3.2.4 Data Interpretation

The results of the multi-well tracer test will be analyzed using methods appropriate for the specific test conditions. Several methods of analysis are described in the source references listed in SOP GW 2.07.

4.0 SAMPLE HANDLING AND CONTROL

Groundwater samples and tracer standard solutions will be collected during the tracer evaluation test and the multi-well tracer tests. Samples to be submitted for laboratory analysis include tracer standard solutions and the groundwater sample collected at the site of the tracer evaluation test prior to the startup of this test. The analytes to be evaluated are described in Section 3.1.1 of this memorandum. If bromide is selected for the conduct of the multi-well tests, groundwater samples for confirmation of the bromide breakthrough curves will also be submitted for laboratory analysis. All other fluids will be analyzed in the field by appropriately calibrated instruments.

Samples to be submitted for laboratory analysis will be collected in precleaned sample containers. Appropriate preservatives will be added to the groundwater sample collected during the collection process to enable proper laboratory analysis. No other fluids will be preserved. The preservation requirements, holding times, and analysis methods for samples to be submitted to the laboratory will conform with those listed in the Site-Wide Quality Assurance Project Plan (QAPjP) for RFP, the Quality Assurance Addendum (QAA 1.1) for

OU1, and the Phase III RFI/RI Work Plan for OU1. Additional information on containerizing, preserving, handling, and shipping of water samples and tracer fluids is given in SOP FO.03 and SOP GW.06.

5.0 DOCUMENTATION

Documentation for each of the field tracer tests described in this technical memorandum will include the following information as a minimum:

- Tracer test approval form (with approval obtained before the test is initiated)
- Field tracer test data sheets that record pertinent water level, flow rate, specific conductance, tracer concentration, temperature, and instrument measurements for each test
- Data logger files of groundwater levels
- Field sample data sheets and chain-of-custody forms
- Field notebook entries that include as a minimum project name, observer's name, date, time, weather conditions, location, and well identification numbers, distances between wells, time and date of relevant information or events (such as test startup, end, etc.), tracer used, tracer concentration, flow rates, decontamination procedures, sampling, and other relevant information.
- Instrument calibration records and supporting data.

6.0 REFERENCES

The complete list of source references is cited in SOP GW 2.07.