UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
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ATLANTA, GEORGIA 30303-8960

March 6, 2016

Ms. Tracey Duncan
Federal Facility Agreement Manager
United States Department of Energy
Portsmouth/Paducah Project Site Office
5501 Hobbs Road
Kevil, KY 42053

RE: U.S. EPA Region 4 Comments on: **Treatability Study Report for the C-400 Interim Remedial Action Phase IIb Steam Injection Treatability Study at the U.S. Department of Energy Paducah Gaseous Diffusion Plant (DOE/LX/07-2202&D1), Issued December 21, 2015,** EPA ID KY8890008982, McCracken County, KY

Dear Ms. Duncan,

The U. S. Environmental Protection Agency (EPA) Region 4 has reviewed the Treatability Study Report for the C-400 Interim Remedial Action Phase IIb Steam Injection Treatability Study at the Paducah Gaseous Diffusion Plant (PGDP). EPA is providing General Comments and Specific Comments to the Department of Energy (DOE) as an enclosure to this letter in support of discussion and document revision. In general, the report accurately documents the results of the field scale steam injection that was carried out from April to June, 2015. EPA's comments address concerns related to the modeling that was performed, the conceptual design of the full scale Steam Injection system, and the estimated costs. EPA recommends additional modeling effort to develop an optimal design for full scale deployment of the steam injection and extraction system. While Steam Injection appears successful from a technical perspective in heating the subsurface, including the Lower Regional Gravel Aquifer (RGA), the lack of cost information in the report makes it difficult to evaluate future full scale deployment of Steam Enhanced Extraction of TCE from a cost effectiveness perspective.

If you have any questions about this correspondence, please do not hesitate to contact me at (404) 562-8547 or via electronic mail at corkran.julie@epa.gov.

Sincerely,

Julie L. Corkran, Ph.D.
Federal Facility Agreement Manager
Superfund Division

Enclosure

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United States Environmental Protection Agency (U.S. EPA) Region 4
Comments on:

Treatability Study Report for the C-400 Interim Remedial Action Phase IIb Steam Injection Treatability Study at the U.S. Department of Energy Paducah Gaseous Diffusion Plant (DOE/LX/07-2202&D1), Fluor Federal Services, Inc, December 21, 2015

EPA ID KY8890008982, McCracken County, KY

Comments submitted by: Eva Davis, Ph.D., USEPA National Risk Management Research Laboratory, Ground Water and Ecosystems Restoration Division, Ada, OK.

General Comments

1. Based on the discussion in Section 4.1.2.5, it appears that only one three dimensional (3D) simulation of the full scale system was performed. If this is the case, it is not clear how the design can be confirmed to be optimum: no other possible designs were simulated to determine if there is a better, more cost effect design or operational strategy to rapidly heat the target treatment area. The layout of the steam injection and extraction system shown in Figure 31 and Drawing M5E-FA1530-A02 would appear to be less than optimal, considering the presence of extraction wells at the outside limits of – or outside of – the target treatment area, and the placement of many steam injection well pairs at distances of 10 to 20 feet from the target treatment area (see comment #8). The 3D modeling effort reported also does not include a sensitivity analysis.

   A sensitivity analysis should be provided in the revised report. Without a sensitivity analysis on the full scale model, it cannot be determined how different values for the parameters may have affected the model results, and thus the determination of the adequacy of the proposed design and operational strategy.

2. Section 2.1.8 and Section 4.3.2 present the range of the estimated total costs for full-scale implementation of steam injection. The costs of $1,265/yd^3 – $2,703/yd^3 is at least an order of magnitude greater than the typical costs for thermal remediation, which are typically in the range of $100 – $150/yd^3. However, it may be appropriate to compare these unit costs to those of other Interim Action remediations that have been completed at building C-400 to determine it the costs are 'reasonable'–or within the range that can be expected–for the Paducah facility.

   EPA recommends that the entire engineering cost estimate be provided as part of the report for review.

3. Section 4.1.2 on page 59 states that 'steam injection wells extend about 30-40 ft beyond the edge of the Phase IIb treatment area on the south half of the pattern . . . to maximize contaminant removal.' Section 4.3.1 on page 71 states, 'Based on lessons learned from previous investigations . . . a roughly 20-ft wide additional treatment zone around the perimeter of the southern portion of the area used during the TS Design was added to

maximize contaminant removal. Based on review of the continuously cored boring logs of the injection well cluster . . . southernmost extent of the suspected treatment area is near Tennessee Avenue'. Also, Figure 31 and Drawing M5E-FA1530-A02 appear to show the treatment area extending beneath Tennessee Avenue. Please explain in detail why it is believed that extending the treatment area to the south will maximize contaminant removal, and what in the soil boring logs indicates that the southernmost extent of the suspected treatment area is near Tennessee Avenue.

If additional contamination outside of the originally proposed treatment area (as shown on Drawing C7DC40000A027) was found during the installation of wells for the TS, or if it is commonly found that past delineations of contaminant extent were faulty, then perhaps additional characterization should be undertaken surrounding the entire treatment area to determine the appropriate treatment area.

Specific Comments

1. Section 4.1.2 states that major steam breakthrough in most wells occurs between five and ten days after the initiation of steam injection. This is a much shorter time for steam breakthrough at the extraction wells than is commonly used at SEE sites. The problem that this creates is that the steam reaching the extraction wells and extracted from the system is essentially wasted energy – it does not contribute to heating the formation or the contaminants and therefore does not contribute to the recovery of contaminants. According to Figure 43 and the discussion on page 69, during the last 70 days of steam injection, approximately 84% of the injected energy would be extracted. It is recommended that the operational strategy be modified to heat the target zone more uniformly, so that breakthrough at the extraction wells occurs more uniformly, reducing the need to continue injecting steam at a high rate after partial steam breakthrough at the extraction wells has occurred in order to heat the entire treatment zone. Also, the operational strategy should include pressure cycling to help reduce the amount of steam that is wasted and to improve contaminant recovery from low permeability zones (Ref: (Udell, K. S., and L. D. Stewart, Combined steam injection and vacuum extraction for aquifer cleanup, In: Subsurface Contamination by Immiscible Fluids, Weyer, K. U., ed., Proceedings of the International Conference on Subsurface Contamination by Immiscible Fluids, Calgary, Canada, April 18-20, 1990).

   EPA recommends that the operational strategy in the report be revised to (i) heat the target zone more uniformly and (ii) include pressure cycling.

2. Section 4.3.1.3 gives a design extraction rate of 3 gallons per minute (gpm) per each of the 17 dual phase extraction (DPE) wells for the full scale design, and states that the purpose of this extraction is to ensure an inward and upward gradient to account for the additional water that will result from steam condensation. However, Section 4.1.2 on page 59 states that the simulation of the full scale design assumed a steam injection rate of 1,000 pounds per hour (lbs/hr) for each of the deep injection wells, and 500 lbs/hr for each shallow injection well initially, making a total injection rate of 34,500 lb/hr – or approximately 69 gpm – for the 23 injection wells. Thus, the design as presented calls for

injecting more water (condensed steam) during the first 20 – 45 days (depending on whether you go by the duration given in Section 4.1.2 or 4.3.1.2) than will be extracted, and outward migration of water from the treatment zone will occur. Once a steam zone is established and as it grows, considerably more water will be displaced from the steam zone, as water expands by a factor of approximately 1700 as it vaporizes to steam, which would force greater amounts of water out of the steam zone. Typical extraction rates used at other SEE sites have ranged from 3 to 10 times more water extracted than injected as steam.

3. Section 4.3.2.2 states that the theoretical minimum energy requirement is 110,000 BTU/yd^3 (32 kilowatt hours per cubic yard (kWh/yd^3)). Based on expected steam injection rates and durations provided here and in Section 4.1.2, it appears that the planned total steam injection is planned to be approximately 107 – 130 lbs/yd^3. The planned energy usage is considerably less energy that has been used at other SEE sites for which this reviewer has provided oversite. As a general rule, 150 – 200 kWh/yd^3 are required for thermal remediation, and steam injection quantities are about 700 lb/yd^3.

4. Section 4.3.2.2 states that comparable remedial projects were reviewed to corroborate the total project cost estimate. Please provide for Agency review all the information on other remedial projects that were reviewed to make this determination.

5. Figure 31 and Drawing C7DC40000A027 show 3 steam injection well pairs (SIW-19, SIW-21, and SIW-23) which are approximately 20 feet from the target treatment zone. Since the injection wells are expected to have a radius of influence of 20 feet, essentially none of the steam injected in these wells is expected to enter the target treatment zone. Several of the other proposed steam injection well pairs (SIW-13, SIW-17, SIW-20, and SIW-22) are far enough away from the treatment zone that very little of the steam injected in these wells would be expected to enter the treatment zone. Thus, the steam injected in these wells would not be expected to substantially increase the amount of contaminants extracted, if the target treatment zone is defined correctly (in which case, there would not be substantial contaminants outside of the treatment area). Please revise the report to provide the rationale for these proposed steam injection well pairs.

6. Figure 31 and Drawing C7DC40000A027 show 9 of the 33 TMPs to be located outside of the target treatment zone, but within the radius of influence of a steam injection well. It is not clear what useful data these TMPs will provide. If there is a desire to know if significant quantities of steam are leaving the treatment area, these exterior TMPs should be outside of the expected influence of steam injection wells. Please revise the report to provide the rationale for proposed locations of the 9 TMPs.

7. Appendix E, on page 10, states that the layered permeability structure of the Regional Gravel Aquifer (RGA) was the primary calibration variable used to match the field data. Please revise the report to discuss the other calibration variables that were used.

8. Appendix E, on page 10, provides the values that were used for the parameters in the van Genuchten model for capillary pressure. The values given are similar to those found for a silt loam or loam soil (van Genuchten, 1980). What is the justification for using these values for the RGA, which is likely far more permeable than a loam soil? Please perform a sensitivity analysis and demonstrate the effects of the van Genuchten parameters on the results of the 3D model.

9. Appendix E, on page 10, provides the values used in the models for the rock grain density, porosity, rock grain heat capacity, and dry bulk thermal conductivity. Please provide an analysis to demonstrate the sensitivity of the model to the values of these properties used in the 3D model.

10. Appendix E, on page 13, states that TMP 9 and TMP 10 were both 10 feet from the injection well. Please correct this to state that these wells were 20 feet from the injection well.

11. Appendix E must include a sensitivity analysis on the calibration of the 3D model, with an explanation of how different values for the model parameters over the range of which they are expected to vary, will affect the results of the 3D simulation of the full scale steam injection.

Comments submitted by: TechLaw, EPA Region 4 ROC Contractor

General Comments

1. <u>Insufficient information is provided in the Treatability Study Report to support the treatability study (TS) conclusions and recommendations</u>. For example:

   a. Table 1 (Full-Scale Deployment Design Criteria) indicates that the thermal radius of influence (ROI) for wells screened in the Lower Regional Gravel Aquifer (RGA) proposed for the conceptual model for full-scale implementation is 20 feet (ft); however, it is unclear why this ROI was selected given that the 2D RZ Simulations – TS Phase 1 Model Calibration subsection of Section 4.1.2.4 (Two Dimensional Modeling of the TS) states that "field data indicate that the steam flow is not radially symmetric. For example, both TMP [temperature monitoring point] 6 and TMP 7 are located 10 ft from the steam injection well, but they show very different temperature responses. Similarly, both TMP 9 and TMP 10 are located 20 ft from the injection well, but they also show different temperature responses." Similarly, Section 2.1.3 (Steam Front Migration) indicates that the steam front extent reached beyond 15 ft but did not reach 20 ft in the RGA during the initial TS steam injection.

   b. The TS Phase 1 – Initial Steam Injection subsection of Section 2.1.3 states, "Horizontal migration of the steam front proceeded from both the upper and lower screens at slightly different rates of outward migration;" however, the rates of outward migration are not specifically provided to substantiate that the rates were slightly different.

   c. The TS Phase 1 – Initial Steam Injection subsection of Section 2.1.3 states, "Outward migration of the steam front proceeded slightly faster in the Upper RGA than in the lower RGA;" however, the specific rates of outward migration are not specifically provided to substantiate that the rates were slightly faster in the Upper RGA than in the lower RGA.

   d. The TS Phase 2 – Initial Cool Down subsection of Section 2.1.3 indicates that the cooling rates were greater in the Lower RGA then in the Upper RGA; however, the specific rates of cooling are not specifically provided to substantiate that the rates were greater in the Lower RGA then in the Upper RGA.

   e. Item 2 of Section 2.1.5 (Lessons Learned) states, "The 3D simulations determined that lowering the upper screen by 6.5 ft resulted in a more even heat distribution in the RGA and could be implemented during full-scale deployment;" however, information beyond modeling that lowering the upper screen by 6.5 ft would result in a more even heat distribution in the RGA is not provided.

   f. Section 4.1.1.5.1 (TS Phase 1 – Initial Steam Injection) states, "The steam front propagation was dominantly horizontal from both the upper and the lower screens during the first 10 days of Phase 1, and no temperature sensor evidence of rapid heating from the lower screen to the base of the UCRS [Upper Continental Recharge System] was observed;" however, Figure 4 (Subsurface Temperatures Measures in TMP-01 during TS

Phase 1 – Initial Steam Injection) shows rapid heating from 80 to 85 ft below ground surface after April 9, 2015.

g. Based on Drawing M5E-FA1530-A02 (Full Scale Conceptual Site Plan) of Appendix C (Drawings), it is unclear if sufficient TMPs are proposed for the conceptual design for the full-scale implementation. For example, no TMPs are located in the vicinity of SIW-15S/SIW-15D or SIW-23S/SIW-23D.

Revise the C-400 TS to provide and/or reference information to support the TS conclusions and recommendations.

2. As noted in Section 3.4 (Data Collection and Analysis), the objectives of the TS are to understand the response of the RGA to steam injection and determine the effect of groundwater flow on heating of the RGA; however, Section 4 (Results and Discussion) does not specifically discuss the response of the RGA to steam injection or the effect of groundwater flow on heating of the RGA. While it is understood that modeling indicated that regional groundwater flow played only a small role in the movement of the steam front, the C-400 TS does not discuss the effect of groundwater flow on heating the RGA.

   Revise the C-400 TS to specifically discuss the response of the RGA to steam injection and the effect of groundwater flow on heating of the RGA.

3. While Sections 4.3.2 (Engineer's Cost Estimates) and 4.3.2.2 (Cost metrics) discuss the estimated costs associated with the conceptual design for full-scale implementation of steam-enhanced extraction (SEE), the C-400 TS does not discuss the costs associated with implementing the TS. As such, the C-400 TS does not provide information to support the estimated costs discussed in Sections 4.3.2 and 4.3.2.2. For example, Section 4.3.1.2 (Steam generation system) states that, "The boiler rental rate was maintained in the estimate, but the natural gas cost was eliminated;" however, the specific costs are not provided to determine if the omission of the natural gas costs directly impacts the cost estimate. The engineer's cost estimate for the full-scale implementation is not sufficiently detailed in the report and provides too large of a range of costs to provide a clear evaluation of the cost effectiveness for future full scale deployment of the technology.

   Revise the C-400 TS to discuss the costs associated with implementing the TS. In addition, revise the C-400 TS to provide and/or reference information to support the estimated costs associated with the conceptual design for full-scale implementation of SEE.

4. Based on Section 1.1.3 (Prior Removal and Remediation Activities) and Appendix A (Variance Letters), 12 electrode wells, located within the footprint of the TS area which were associated with a completed three-phase electrical resistance heating (ERH) interim remedial action (IRA), were plugged; however, the C-400 TS does not discuss the remaining 82 electrode wells. In addition, the C-400 TS does not discuss if the abandonment of the 12 electrode wells had any impact on the TS (e.g., short-circuiting).

Revise the C-400 TS to discuss the abandonment of the electrode wells and if the abandonment had any impact on the TS or is expected to impact full scale implementation of the steam technology in the C-400 Building area.

5. Several field change requests (FCRs)/field change notices (FCNs), provided in Appendix C (Drawings), are not discussed in the text. Revise the C-400 TS to discuss all FCRs/FCNs and their impact on the TS and potential impact on full-scale implementation.

6. The Utility Bridge & Foundation Details drawing provided in Appendix C (Drawings) is unreadable. Revise Appendix C to ensure all drawings are readable.

7. While a summary of the lessons learned is included in Section 2.1.5 (Lessons Learned), insufficient information is provided to determine whether the lessons learned were captured to support a conceptual design for full-scale implementation of SEE. In addition, there was some information that was obtained during the TS but not included in Section 2.1.5 or incorporated into the conceptual design. For example:

   - The C-400 TS indicates that the steam flow is not radially symmetric; however, this is not noted in Section 2.1.5 nor does it appear to be incorporated into the conceptual design in determining a radius of influence (ROI).
   - The use of a phased injection is part of the C-400 TS; however, a phased or cyclical approach to a conceptual full-scale system is not proposed.

Specific Comments

1. Section 1.4, Previous Treatability Studies at the Site, Pages 6-7. Section 1.4 documents the previous treatability studies conducted at the site, but does not discuss the lessons learned and issues encountered.

   Revise Section 1.4 to discuss the lessons learned and issued encountered during the previous treatability studies conducted at the site so that the information can be incorporated into future remedial actions.

2. Section 2.1.1, Lithology and Hydrogeology, Page 9. Given the impact of lithology and hydrogeology on the effectiveness of the TS, it is unclear why uncertainty exists regarding the groundwater pore velocity. Specifically, the fourth bullet of Section 2.1.1 states, "Groundwater pore velocity in the study area likely is on the order of 0.1 to 0.3 ft per day."

   Revise the C-400 TS to clarify why uncertainty exists regarding the groundwater pore velocity.

3. Section 3.6.5, Substitution of Class H Cement for Class G Cement, Page 22. Section 3.6.5 indicates that Class G and Class H Portland cements are equivalent per the API specifications. However, the API definitions provided for Class G and H for Class G Portland

cements differ. The primary difference for Class G Portland Cement is listed as "finely ground cement" while the primary difference for Class H Portland Cement is listed as "courser ground cement."

Revise Section 3.6.5 to clarify how these cements are equivalent when the API definitions differ.

4. Section 4.1.1.5.1, TS Phase 1 – Initial Steam Injection, Page 26. Section 4.1.1.5.1 states, "Once the functionality of the system was verified, the injection rate was increased to the design rate of 500 pph [pounds per hour];" however, the text does not discuss how the system functionality was verified.

   Revise Section 4.1.1.5.1 to clarify how the system functionality was verified so that the injection rate could be increased to the design rate of 500 pph.

5. Appendix C, Drawings, Drawing Number P7DC40000A060 (Treatability Study Piping & Instrumentation Diagram). Drawing Number P7DC40000A060 (Treatability Study Piping & Instrumentation Diagram) includes several red triangles (01S-01, 01S-02, 01S-03, 01S-04, 01S-05, 01S-06, 01S-07, 01S-08, 01S-09, 01S-10, 01S-11, 01S-12, 01S-13, 01S-14, 01S-15, 01S-16, 01S-17, 01D-01, 01D-02, 01D-03, 01D-04, 01D-05, 01D-06, 01D-07, 01D-08, 01D-09, 01D-10, 01D-11, 01D-12, 01D-13, 01D-14, 01D-15, 01D-16, 01D-17, M-01, M-02, M-14, M-15, M-16, and M-17); however, the meaning of these red triangles is not provided and/or referenced.

   Revise Drawing Number P7DC40000A060 to clarify the meaning of these red triangles.

6. Appendix F, Standard Operating Procedures. Section 4.2 (Quality Assurance/Quality Control) states, "The standard operating procedures documented in the LATA Kentucky [LATA Environmental Services of Kentucky, LLC] *Health and Safety Plan*, and the *Treatability Study Steam Injection Shakedown and Startup Procedure* (LATA Kentucky PAD-400-0048) were used along with applicable LATA Kentucky procedures to implement the work (Appendix F, Standard Operating Procedures);" however, Appendix F only includes the Health and Safety Plan and Treatability Study Steam Injection Shakedown and Startup Procedure Subcontractor Submittal. No other standard operating procedures (SOPs) are provided.

   Revise Appendix F to include all applicable SOPs for the TS.