Independent Technical Review Report

Review of Proposed On-Site Disposal Facility at the Paducah Gaseous Diffusion Plant

By Craig H. Benson, PhD, PE; William H. Albright, PhD; David P. Ray, PE; and John Smegal

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1. INTRODUCTION

The Paducah Gaseous Diffusion Plant (PGDP) is an active uranium enrichment facility that is owned by the US Department of Energy (DOE). Uranium enrichment facilities at PGDP are leased to and operated by the United States Enrichment Corporation. In 1994, PGDP was placed on the National Priorities List. Consequently, DOE is required to remediate PGDP in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A Federal Facilities Agreement (FFA) was created in 1998 to define the regulatory framework for remedial activities at PGDP.

DOE is evaluating alternatives to dispose of wastes generated from the remedial activities at PGDP. One option is to construct an on-site disposal facility (OSDF) meeting the applicable or relevant and appropriate requirements (ARARs) as defined by CERCLA. In effect, this will require that the OSDF have the characteristics of a RCRA Subtitle C landfill, while also meeting the requirements of DOE Order 435.1. A preliminary design for the OSDF has not been developed.

DOE requested that an Independent Technical Review (ITR) team provide input on several lines of inquiry (LOI) related to the proposed OSDF at PGDP. These LOI are:

1. What is the most effective use of the currently operating RCRA Subtitle D landfill (C-746-U) if a CERCLA waste disposal facility is approved and constructed?

2. The US EPA, the public, and State Natural Resource regulators favor siting the proposed facility in a brownfield area to avoid expanding the overall footprint of negative impact. State solid waste regulators insist that brownfield sites are inappropriate because background contamination would complicate ground water monitoring of the proposed facility. Are there lessons learned from elsewhere in the DOE complex that could be used to resolve this stakeholder dispute?

3. Is existing seismic information for the Paducah site adequate to assess seismic risk and to design a facility accordingly?

4. What are potential public uses of a closed CERCLA cell?

5. Is the public communications plan effective and sufficient?

6. Is the baseline schedule realistic when compared to the actual and forecasted progress for other CERCLA Cells in the DOE complex?

These LOI were addressed by an ITR team comprised of Craig H. Benson, PhD, PE (University of Washington; Seattle, WA), William H. Albright, PhD (Desert Research Institute; Reno, NV), David P. Ray, PE (US Army Corps of Engineers; Omaha, NE), and John Smegal (Legin Group; Washington, DC). This group, which has expertise in waste containment, civil engineering, geotechnical engineering, and project management, addressed the LOI by conducting a site visit on 28 May 2008, reviewing documents provided by DOE personnel at PGDP, and based on the experience of the ITR team. Findings of the ITR team for each of the LOI are described in the following sections.

2. LINE OF INQUIRY NO. 1

What is the most effective use of the currently operating RCRA Subtitle D landfill (C-746-U) if a CERCLA waste disposal facility is approved and constructed?

The existing Subtitle D landfill has an appreciable amount of permitted airspace that could be valuable during remedial activities at PGDP. Two uses are anticipated to be most important: (i) diversion of non-hazardous and non-radioactive wastes from the OSDF and (ii) temporary storage of wastes and debris in lined areas prior to permanent disposal in the OSDF.

Diversion of wastes to the Subtitle D landfill could reduce the required size and cost of the OSDF. These wastes might include non-contaminated debris, materials with a sufficiently low degree of contamination to meet the disposal requirements in Subtitle D, and potentially some very low activity radioactivity wastes that meet the Waste Acceptance Criteria (WAC). However, the economic viability of diverting wastes to the Subtitle D landfill would need to be considered carefully. Although the lifecycle cost for disposal in the Subtitle D landfill should be lower than in the OSDF, diversion of wastes may require additional testing to demonstrate suitability for disposal in a Subtitle D landfill as well as additional approvals from the regulatory agency. Meeting these requirements may adversely affect scheduling of disposal operations. The additional haul distance to the Subtitle D landfill and the additional cost associated with separating non-RCRA D and RCRA D wastes may also affect whether waste diversion is economical. Finally, stakeholders may take exception to using the Subtitle D landfill for wastes from remedial action. Stakeholder perceptions and relationships are critical when proposing and operating an OSDF, and the costs saved by waste diversion could be offset by inefficiencies imposed by stakeholder concerns.

Use of the Subtitle D landfill as a staging area prior to permanent disposal may be the best and most viable option. Experience at other DOE sites has indicated that careful sequencing of waste streams can optimize the use of air space and reduce the amount of non-contaminated material that is used in an OSDF for disposal operations. Use of the Subtitle D landfill as a staging area

would require completion of an empty cell and collection and treatment of leachate from the cell. An exemption from the regulatory agency would also be required before non-RCRA D wastes could be placed in a Subtitle D landfill cell, even if the wastes were stored temporarily prior to permanent disposal in the OSDF. Obtaining this exemption should not be problematic given that the wastes would be stored in the cell temporarily, and that operation of a storage and sequencing area would improve operation and long-term performance of the OSDF. However, DOE may be required to define "temporary" precisely (e.g., maximum storage times, etc.). In addition, documenting compliance with a temporary-status condition may require the use of a computerized waste inventory management system.

The Subtitle D landfill does pose an additional long-term risk to DOE. Thus, removing the Subtitle D landfill completely may also be considered, with the exhumed waste placed in the more secure OSDF. Wastes in the older adjacent dump sites could also be exhumed and placed in the OSDF. Interring all of these wastes in a single landfill with a robust design would reduce the likelihood that future remedial actions will be necessary. However, the reduction in risk gained by exhuming and relocating wastes in the OSDF would have to be weighed against risks imposed by the exhumation and re-disposal process. These risks would include increased worker safety issues as well as the environmental impacts associated with removal, transport, and re-disposal of the exhumed wastes.

3. LINE OF INQUIRY NO. 2

The US EPA, the public, and state natural resource regulators, favor siting the proposed facility in a brownfield area to avoid expanding the overall footprint of negative impact. State solid waste regulators insist that brownfield sites are inappropriate because background contamination would complicate ground water monitoring of the proposed facility. Are there lessons learned from elsewhere in the DOE complex that could be used to resolve this stakeholder dispute?

Consensus on this issue has not been established, and decisions are largely made on a site-by-site basis. For example, this issue is unresolved at the Portsmouth Gaseous Diffusion Plant and a clean site was selected for Oak Ridge's Environmental Management Waste Management Facility.

The ITR team believes that a decision on this issue must hold environmental protection paramount and simplicity in monitoring secondary, because environmental protection is *the purpose* of remedial actions and solid waste regulations. From this perspective, using a brownfield site is the most logical and compelling option. A brownfield site is already contaminated to some degree, and thus is more suitable than a clean site for a waste disposal

facility. This argument is far more compelling than avoiding complexities encountered in ground water monitoring due to the presence of pre-existing contaminants. This is particularly true for brownfield sites where active remediation is not required and monitored natural attenuation is a viable and acceptable remedy. For such sites, monitoring of groundwater outside the perimeter of the landfill should provide an adequate measure of ongoing natural attenuation of contaminants in the groundwater. Others measures (e.g., inclined boreholes) could also be used to provide monitor natural attenuation processes beneath the landfill, if necessary.

The OSDF will need to meet ARARs for containment facility design as defined by RCRA Subtitle C. These requirements include a double-liner system with a leak detection zone between the liners. This leak detection zone can be used to monitor the efficacy of the containment system in a much more effective manner than a ground water monitoring system. DOE may also consider proposing innovative schemes that permit monitoring directly beneath the landfill (i.e., the vadose zone between the lower most liner and ground water). For example, a secondary detection zone might be installed directly beneath the lowermost liner of the OSDF along with a series of suction lysimeters in the vadose zone. This approach would also require that DOE, the regulatory agencies, and other stakeholders agree on water quality criteria and trigger levels for the vadose zone in lieu of ground water criteria.

Use of a brownfield site for an OSDF does pose a higher risk of worker exposures relative to construction at a clean site. The importance of these risks would need to go into an evaluation of the suitability of brownfield site. However, these risks would be limited almost exclusively to the period during which the OSDF is constructed. Once the liner systems and haul roads are in place, worker risks should be no different at a brownfield site than at a clean site. Risks during construction could be minimized via a thorough site characterization prior to construction and carefully crafted operating and construction procedures.

4. LINE OF INQUIRY NO. 3

Is existing seismic information for the Paducah site adequate to assess seismic risk and to design a facility accordingly?

The US Army Corps of Engineers (USACOE) provided technical support on LOI No. 3. The discussion below is a summary of their findings. Reports provided by USACOE are included in the appendix.

A conference call was held on 12 June 2008 with representatives of DOE and their contractors, the USACOE, the US Environmental Protection Agency, and the State of Kentucky to address outstanding issues pertaining to the seismic analysis for PGDP. These outstanding issues are:

- suitability of a hybrid deterministic-probabilistic analysis method,
- need for a site-specific shear wave velocity for the bedrock,
- suitability of 0.5 g as a threshold for liquefaction,
- need for the distribution of blow counts, and

USACOE recommends that the seismic ground motion be modeled using both wholly deterministic and wholly probabilistic methods to eliminate any concerns regarding use of a "hybrid" method. Findings obtained using both methods will be complimentary and provide assurance that the ground motion study is consistent, accurate, and realistic.

USACOE recommends that a sensitivity analysis be conducted to assess the need for a site-specific shear wave velocity for the bedrock. A realistic range of shear velocities would be estimated, and the corresponding peak ground accelerations (PGAs) determined. If the bedrock shear wave velocity does not appreciably impact the PGA, then a bedrock shear wave velocity could be selected that provides a conservative PGA for design and liquefaction evaluation. In contrast, if the bedrock shear wave velocity has an appreciable impact on the PGA, the design criteria and liquefaction potential could be evaluated using the range of PGAs from the sensitivity analysis. Results from this analysis would then be used to evaluate whether a site-specific bedrock shear velocity is needed to develop an economical design or to assess the potential for liquefaction reliably. The PGAs obtained from this analysis will also resolve the liquefaction threshold issue.

USACOE recommends that SPT N-values (blow counts) or seismic cone penetrometer testing (SCPT) results be individually evaluated rather than grouped into zones to obtain average SPT or SCPT values. This approach permits a more detailed assessment of the distribution of liquefiable and non-liquefiable materials (both vertical and horizontal extent). USACOE also recommends that cross-sectional and plan view drawings be constructed that identify liquefiable soils. These drawings will be useful in selecting an appropriate site for the OSDF.

5. LINE OF INQUIRY NO. 4

What are potential public uses of a closed CERCLA cell?

Acceptable public uses of the closed CERCLA cell will be influenced strongly by the solid waste agency's perceived effectiveness of the containment facility and DOE's tolerance for risk

associated with public use of the land. The most risk averse scenario is to completely prohibit public use of the closed OSDF. However, community stakeholders may perceive this scenario negatively if there is strong community interest in green space for public use.

The OSDF will need to meet RCRA-C ARARs and the requirements of DOE 435.1. This will require implementation of a thick cover system employing multiple hydraulic barriers and a biota intrusion layer. As a result, the likelihood that the public will ever be exposed to contaminants contained within the OSDF is extremely small. Consequently, the risks incurred through controlled recreational activities on the closed OSDF should be minimal. The lowest risks generally are associated with uses that reduce the number of persons visiting the site and the level of maintenance associated the application.

There is precedent for public use of landfills owned by the Department of Defense that have RCRA-C covers. For example, at the Portsmouth Naval Shipyard, a landfill final cover includes baseball fields and a 12-ac parking lot. A compilation of public uses of closed landfills owned by the Department of Defense can be provided by the Corps of Engineers.

Recreational and light industrial uses could be selected for the OSDF. Recreational uses range from low intensity applications such as a nature park with walking trails to high intensity applications such as athletic facilities (e.g., soccer fields, baseball park, disc golf course). Light industrial uses include parking lots or storage facilities for operations that will continue at the site after remediation activities are complete.

The preferred alternative generally is light duty park space where human interaction is limited primarily to walking trails. This option generally has the lowest costs associated with initial capital investment and long-term maintenance, and provides the greatest control over public movement on the site. Consequently, this option has the lowest risk. Dog parks and mountain bike courses have become popular in recent years, but they have high maintenance costs. They also act as a focal point that draws people to the facility, which generally is undesirable and results in greater risk.

While attractive to communities, athletic facilities tend to be expensive to construct and require a high level of maintenance. Disc golf parks are known to be particularly maintenance intensive. Moreover, as with dog parks, athletic fields act as a focal point that draws people to the facility (e.g., for tournaments). Thus, athletic facilities are not recommended.

Light industrial facilities are less attractive than recreational facilities, but are more practical in terms of ensuring limited interaction with the site and low maintenance costs. However, settlement of waste can affect light industrial facilities, resulting in higher maintenance costs

than normally associated with traditional locations. These additional maintenance costs would need to be considered if an OSDF was selected for light industrial uses.

Any public use strategy that is selected should preclude public access to areas with appurtenances (e.g., drainage layer outfalls, storm water structures, monitoring points) and should prevent the public from disturbing the cover profile. Restrictions should be imposed that require DOE (or a designee) approval for landscaping, earthwork, or other activities that could disrupt the cover.

6. LINE OF INQUIRY NO. 5

Is the public communications plan effective and sufficient?

Communication with stakeholders is one of the most important activities affecting successful siting of an OSDF. Engaging stakeholders and treating them as partners in the siting process is key to eliminating resentment and activities that slow down or stop the process. The ITR believes that the communication plan for PGDP could be enhanced to increase stakeholder involvement and to improve partnerships between stakeholders and DOE.

DOE should assist in the formation of public stakeholder groups that are autonomous, free to speak, and unfettered. This will provide a venue for stakeholders to express their opinions within a structure that is suitable to DOE. Opposition groups may also form independent of DOE's efforts. Each group should be given ample opportunity to ask questions and be heard on their issues. DOE will need to use care to ensure that some groups are not perceived as receiving favorable or greater attention relative to other groups.

Coordinating stakeholder discussion and responses can be a challenge. DOE may consider setting up an independent umbrella group that facilitates interactions between all interested parties and DOE. This group would be funded by DOE under a defined set of guidelines, but would be independently chartered and would not answer to DOE. Lessons learned from other DOE remedial activities may be helpful in indentifying the most effective structure for coordinating and responding to stakeholder issues.

DOE should also provide mechanisms that allow stakeholders not affiliated with a group to voice their concerns and receive responses from DOE. This could be achieved through a combination of a public information website and a staffed telephone number. Providing responses in a timely and thoughtful manner will be important.

Additional discussion on stakeholder involvement can be found in Benson et al. (2008) and Lawless et al. (2008). Benson et al. (2008) includes recommendations made to DOE personnel

at Portsmouth. Lawless et al. (2008) describe recent developments in stakeholder involvement in radioactive waste disposal in the UK and US.

7. LINE OF INQUIRY NO. 6

Is the baseline schedule realistic when compared to the actual and forecasted progress for other CERCLA Cells in the DOE complex?

The ITR reviewed the baseline schedule and found no problematic issues. However, a detailed comparison was not made between the baseline proposed for PGDP and other sites in the DOE complex. A comparison of that type is outside the scope of the ITR.

A review of the proposed and actual baseline schedules at Fernald is recommended. A comparison may identify tasks that are more problematic to schedule accurately. The ITR also recommends that the actual schedule at Fernald and the baseline schedule at PGDP be compared, at least for similar tasks. If significant discrepancies exist, personnel involved in Fernald's OSDF should be contacted for discussion about their experience.

8. RECOMMENDATIONS

The following recommendations are made by the ITR team regarding the proposed OSDF at PGDP:

- Two uses of the existing Subtitle D landfill are anticipated to be most important: (i) diversion of non-hazardous and non-radioactive wastes from the OSDF and (ii) temporary storage of wastes and debris in lined areas prior to permanent disposal in the OSDF. Diversion of waste needs to be explored to ensure that it is economically viable and acceptable to stakeholders. Use of the existing landfill for temporary storage will permit a more orderly and efficient filling scheme for the OSDF, but will require an exemption or approval from the state regulatory agency.

- DOE may consider removing the existing Subtitle D landfill completely, with the exhumed wastes placed in the OSDF along with wastes exhumed from older dump sites at PGDP. Interring all wastes in a single landfill with a robust design will reduce the likelihood that future remedial actions will be necessary and minimize long-term risks. This reduction in risk would need to be weighed against the increased risks associated with worker safety and the environment (e.g., resource consumption, air pollution, air dispersal) that may be associated with exhumation and re-disposal of these wastes.

- The ITR team believes that a brownfield site is the most logical and compelling location for siting the OSDF. However, impacts on worker safety would need to be considered before a brownfield location was selected for the OSDF.

- DOE may consider proposing innovative monitoring schemes that permit monitoring directly beneath the OSDF (e.g., a secondary leak detection zone beneath the lowermost liner coupled with samplers in the vadose zone). These alternatives to conventional ground water monitoring and assessment could persuade the regulatory agency to allow siting in a brownfield area.

- USACOE recommends that the seismic ground motion be modeled using both wholly deterministic and wholly probabilistic methods to eliminate any concerns regarding use of a "hybrid" method.

- USACOE recommends that a sensitivity analysis be conducted to assess the need for a site-specific shear wave velocity for the bedrock. Peak ground accelerations (PGAs) obtained from this analysis will also resolve the liquefaction threshold issue.

- USACOE recommends that SPT N-values (blow counts) or seismic cone penetrometer testing (SCPT) results be individually evaluated, and that cross-sectional and plan view drawings be constructed that identify liquefiable soils.

- The likelihood that the public will ever be exposed to contaminants contained within the closed OSDF through controlled recreational activities is extremely small. However, any public-use strategy should preclude public access to areas with appurtenances and should prevent the public from disturbing the cover profile.

- The communication plan could be enhanced to increase stakeholder involvement and to improve partnerships with stakeholders. Recommendations for enhancement include the formation of stakeholder groups, development of policies that ensure unfettered communication, and formation of an independent umbrella organization that can address issues from a variety of stakeholder groups.

- The ITR reviewed the baseline schedule and found no problematic issues. Review and comparison of the proposed and actual baseline schedules at Fernald and PGDP by DOE personnel is recommended.

These recommendations should be considered in the context of PGDP's Radioactive Waste Management Basis and Disposal Authorization Statement and the associated conditions imposed by the Low-Level Waste Disposal Facility Federal Review Group. If necessary, an Unreviewed

Disposal Question Evaluation might be conducted or a recommendation could be addressed through appropriate PA Maintenance Plan activities.

9. ACKNOWLEDGEMENT

This technical review was supported by Mark Gilbertson (DOE-HQ), Dinesh Gupta (DOE-HQ), Vincent Adams (DOE-HQ), and Jeff Snook (DOE-PGDP). Owen Robertson (DOE-RL) participated in the site visit and the review. The ITR thanks those individuals with DOE who provided information and input during the review.

10. REFERENCES

Benson, C., Albright, W., and Ray, D. (2007), Review of Issues Associated with the Proposed On-Site Waste Disposal Facility (OSWDF) at Portsmouth, Independent Technical Review Report, US Department of Energy, Washington, DC.

DOE (2001), Radioactive Waste Management Manual, DOE M 435.1-1. Office of Environmental Management, US Department of Energy, Washington, DC.

Lawless, W., Whitton, J., and Poppeliers, C. (2008), Case Studies from the United Kingdom and the United States on Stakeholder Decision Making on Radioactive Waste Management, *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, ASCE, 12(2) 70-78.

APPENDIX – USACOE REPORTS ON SEISMIC ANALYSIS

TO: Craig H. Benson (University of Wisconsin – Madison)
Dinesh Gupta (U.S. Department of Energy)
Edward F. Johnson (U.S. Department of Energy, Contractor)

FROM: Nick Geibel (U.S. Army Corps of Engineers, Geology Section)
Jennifer Grimm (U.S. Army Corps of Engineers, Geology Section)

SUBJECT: Evaluation of outstanding comments submitted by the Kentucky Department of Waste Management on the Seismic Investigation Report for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, (D2 Seismic Investigation Report), [DOE/OR/07-2038&D2], March 2004.

DATE: 5 August 2008

1. A regional and site-specific seismic investigation was completed at the Paducah Gaseous Diffusion Plant (PGDP), Paducah, Kentucky, during the early 2000's by the U.S. Department of Energy (DOE). The purpose of this seismic investigation was to characterize a portion of the Department of Energy's property that is under consideration for the potential siting of a disposal facility for wastes generated from future environmental restoration activities at PGDP implemented under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. The study concentrated on three primary tasks: 1) a paleoliquifaction study, 2) a fault study, and 3) a geotechnical study. Data, evaluation methodologies, findings, and conclusions are presented for each of the three primary tasks in the D2 Seismic Investigation Report.

2. Representatives of various agencies of Kentucky, primarily the Department of Waste Management (KDWM) and Geological Survey, reviewed and commented on the draft version of the report (D1 Seismic Investigation Report version). Upon re-submittal and review of the report (D2 Seismic Investigation Report version), KDWM believes that some of their comments have not been fully addressed in the D2 version of the report. A conference call was held on June 12, 2008, with representatives of DOE and their contractors; U.S. Army Corps of Engineers, Omaha District (USACE); U.S. Environmental Protection Agency; and State of Kentucky to focus on achieving a clear understanding and path forward on resolving KDWM's outstanding comments pertaining to the D2 report. The outstanding comments discussed during the conference call were:

    1) A hybrid deterministic/probabilistic method was used to perform the seismic ground motion modeling in lieu of a purely probabilistic method preferred by some in the seismological community. Kentucky has not yet approved of this hybrid approach.

2) Kentucky expressed concern in the Comment Response Summary regarding DOE's reliance upon a non site specific shear wave bedrock velocity in its calculations. This remains an open issue.
3) Kentucky's comments requested further justification for the presumed 0.5 g liquefaction threshold value.
4) A map was requested showing the distribution of blow count data within Site 3A. Blow counts recorded during the geotechnical portion of the study provide information relating to the stability of Site 3A soils.

3. The purpose of this memorandum is to provide an independent technical evaluation of the outstanding comments presented above for the project team's consideration to aid in their resolution of the comments and strategize a path forward respective of the site's seismic constraints. Each comment listed in paragraph 2 above will be addressed below.

    1) Comment: A hybrid deterministic/probabilistic method was used to perform the seismic ground motion modeling in lieu of a purely probabilistic method preferred by some in the seismological community. Kentucky has not yet approved of the hybrid approach. Response: Generally, experts in the field of seismology consider deterministic and probabilistic as incompatible methods (even though attempts have been made to combine the two methods into one workable solution). Seismic ground motion modeling should be performed using an established wholly deterministic or wholly probabilistic method to eliminate the professional contention of using a "hybrid" method. Additionally, consideration could be given to completing the ground motion study using both methods as the results from each method can compliment one another by providing an assurance that the ground motion study results are consistent, accurate, and realistic for their ultimate use in design and liquefaction evaluations. The method(s) to be used could be outlined in a work plan allowing reviewers an opportunity to come to an agreement on the method(s), evaluation techniques, and any associated criteria. This would also allow the opportunity to determine any additional data that needs to be collected in support of the method(s) and engineering calculations (i.e., liquefaction, etc.), where it could also be outlined in the work plan.

    2) Comment: Kentucky expressed concern in the Comment Response Summary regarding DOE's reliance upon a non site specific shear wave bedrock velocity in its calculations. This remains an open issue. Response: Prior to performing any field work to determine a site specific value of the shear velocity for the limestone bedrock, it may be appropriate to perform a sensitivity analysis on this factor in the development of a peak ground acceleration (PGA) that is used in design and liquefaction evaluations. Under this approach, the degree of influence of the shear velocity of the limestone bedrock on the resultant PGA value to be used in design and liquefaction evaluations would be determined. First, a realistic range of the shear velocity for the type of bedrock limestone found at the site could be estimated, then resultant PGA

values could be derived from several shear velocities within the range. If it is determined that the bedrock shear velocity does not appreciably impact the PGA value, then a bedrock shear velocity value could be used to that provides a relatively conservative PGA to be used in the design and liquefaction evaluation phases. If it is determined that the bedrock shear velocity does appreciably impact the PGA value, then the resultant range of PGAs could be used to evaluate design criteria, potential project cost impacts, liquefaction potential, and aid in the determination if a site specific bedrock shear velocity is required to be collected. If after it is determined that a site specific bedrock shear velocity is required, cross-hole, down hole, or seismic refraction geophysical methods could be used to obtain this data. (Based on discussions during the June 12, 2008, conference call, it appeared that KWMD supported first cross-hole then second seismic refraction as favorable bedrock shear velocity evaluation methods and only one site specific location would be required to be evaluated.) Also, if it is determined during work plan development that additional subsurface data is required, it could be collected during any boring program to support cross-hole or down-hole geophysical methods. (Other benefits of performing the sensitivity analysis is that the final evaluation method(s) to determine the PGA to be used for design and liquefaction evaluation will be accomplished through the involvement of all stakeholders, initial design and liquefaction evaluation results can be developed for project cost evaluation, additional data needs are more easily identified through the process, and programs and models are developed allowing site specific results (should they be necessary) to be quickly and efficiently evaluated.)

If the sensitivity analysis approach is not taken, then a site specific bedrock shear wave velocity should be collected to allow the appropriate development of a site specific PGA (based on methodologies outlined in the work plan) used in design and liquefaction evaluations.

3) Comment: Kentucky's comments requested further justification for the presumed 0.5 g liquefaction threshold value. Response: Per discussions during the June 12, 2008, conference call, it appeared that KWMD did not feel their original comment (i.e., requiring additional justification for the development of the 0.5 g liquefaction threshold value) on the D1 Seismic Investigation Report version was adequately addressed in the D2 Seismic Investigation Report version. It seems a simple clarification statement in the D2 report version indicating that certain site soils have the potential for the onset of liquefaction at 0.5 g would suffice to address this concern. Ultimately, using the resultant PGA derived from revised PGA development method(s) as discussed in comment 1 above for the liquefaction evaluation will probably be required.

4) Comment: A map was requested showing the distribution of blow count data within Site 3A. Blow counts recorded during the geotechnical portion of the

study provide information relating to the stability of Site 3A soils. Response: Per discussions during the June 12, 2008, conference call, KWMD indicated they felt it was inappropriate to group site soils into "zones" and evaluate the liquefaction potential based on a single averaged standard penetration test (SPT) value for each zone as was completed in the D2 Seismic Investigation Report version. To fully understand the effects of liquefaction on soils at the site, it is preferable that SPT N-values or seismic cone penetrometer testing (SCPT) results be individually evaluated rather than grouped into zones to obtain average SPT or SCPT values that are then used in liquefaction evaluation. By performing the liquefaction evaluation on individual blow counts, a more detailed distribution of liquefiable and nonliquefiable materials can be determined. This detailed distribution would encompass both vertical and horizontal extents of liquefiable materials which are very useful in determining if liquefaction of soils will be a concern, as some significant vertical and horizontal soil volume would need to be potentially liquefiable to be problematic to the integrity of the landfill cell. Also, by determining the vertical and horizontal extent of potentially liquefiable soils, those soils that are considered problematic will be well defined (where any data gaps can also be identified) for remedial planning efforts. Therefore, it is recommended for consideration that cross sections identifying individual SPT N-values (or individual blow counts) and appropriate SCPT information be constructed. Additionally, it is recommended for consideration that cross sections and plan view figures identifying liquefiable soils be constructed to aid in clear visualization of potential problem areas and development of landfill cell design criteria.

During discussions during the June 12, 2008, conference call, KWMD also indicated that a "simplified" method should be used for the liquefaction evaluation. Based on the conference call discussions it is assumed that the "simplified" method used is that originally developed by H.B. Seed, I.M. Idriss, and Arango and further refined by T.L. Youd and I.M. Idriss (however this assumption would need to be confirmed with KWMD). Based on the review of chapter 5 of the D2 Seismic Investigation Report, it appears that the "simplified" method was utilized to some extent; however it was not clear if a Magnitude Scaling Factor (MSF) and correction factors developed to extrapolate the simplified method for larger overburden pressures (greater than 15 meters) (K_σ) and a correction factor for sites other than level to gently sloping ($K_{\acute{\alpha}}$) to account for existing states of static shear stress in and beneath a slope. These correction factors should be incorporated into this evaluation as necessary. If the earthquake magnitude is determined to be 7.5, then the MSF would be 1 and non-consequential to the factor of safety (FSL) against liquefaction per this "simplified" method. Additionally, if the proposed site is relatively flat then the $K_{\acute{\alpha}}$ correction factor would also be non-consequential and could be ignored. Attachment 1 is a flow chart that shows the "simplified" procedure that KWMD may have been referring to during the conference call. As shown on Attachment 1 safety factors of 1.1 and 1.4 have

been applied to the resultant FSL value, these safety factors could be ignored if deemed unnecessary for purposes of this projects evaluation. A recent publication by T.L. Youd and I.M. Idriss (*J. Geotechnical and Geoenvironmental Engineering*, 127(4), 2001, 297-313) that outlines the procedure shown on Attachment 1 and provides equations for all evaluation factors that can be programmed for ease of use. This Youd-Idriss publication is a summary of the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils.

Recent developments in liquefaction susceptibility of clayey soils are described in Li et al. (*J. Geotechnical and Geoenvironmental Engineering*, 133(1), 2007, 110-115) and Boulanger and Idriss (*J. Geotechnical and Geoenvironmental Engineering*, 132(11), 2006, 1413-1426). Clayey soil types at the site, although generally considered not susceptible to liquefaction, could be evaluated per these criteria, if appropriate data, exists to complement the fine-grained soil evaluation that was performed in the D2 Seismic Investigation Report version.

$R_d = 1.0 - (0.00765 \times z)$ for $z \le 9.15$ m

$R_d = 1.174 - (0.0267 \times z)$ for $9.15 \text{ m} < z \le 23$ m

$R_d = 0.744 - (0.008 \times z)$ for $23 \text{ m} < z \le 30$ m

$R_d = 0.50$ for $z > 30$ m

Step 1) Compute Cyclic Stress Ratio

$$CSR = 0.65 \times \left(\frac{a_{max} \times R_d}{g}\right) \times \left(\frac{\sigma_o}{\sigma_o'}\right)$$

N = uncorrected SPT blows per foot

$C_N = 2.2 / (1.2 + (\sigma_0'/Pa))$

C_E = SPT Hammer Energy Ratio
- Donut Hammer - 0.5 to 1.0
- Safety Hammer – 0.7 to 1.2
- Automatic Trip – 0.8 to 1.3

C_B = Borehole Diameter Correction Factor
- 65 to 115 mm = 1.0
- 150 mm = 1.05
- 200 mm = 1.15

C_R = Rod Length Correction Factor
- < 3 m = 0.75
- 3 to 4 m = 0.8
- 4 to 6 m = 0.85
- 6 to 10 m = 0.95
- 10 to 30 m = 1.0

C_S = Sampling Device Correction Factor
Standard Split-Spoon Sampler w/ liner = 1.0
Standard Split-Spoon Sampler w/o liner = 1.1 – 1.3

Step 2) Determine Cyclic Resistance Ratio by correcting SPT blow counts to $(N_1)_{60}$ blow counts and comparing result to Figure 2. The $(N_1)_{60}$ blow counts are calculated as follows:

$$(N_1)_{60} = N \times C_N \times C_E \times C_B \times C_R \times C_S$$

Step 3) Compute Factor of Safety Against Liquefaction.

$$FSL = \left(\frac{CRR}{CSR}\right) \times MSF \times K\sigma \text{ (Fig. 15)}$$

FSL < 1.1

Yes → Potential Liquefaction

No → 1.1 < FSL < 1.4

Yes → Safe but may be vulnerable to progressive failure.

No → FSL > 1.4

Yes → Generally safe against liquefaction.

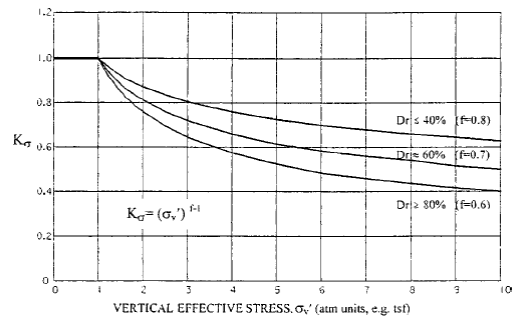

FIG. 15. Recommended Curves for Estimating K_σ for Engineering Practice

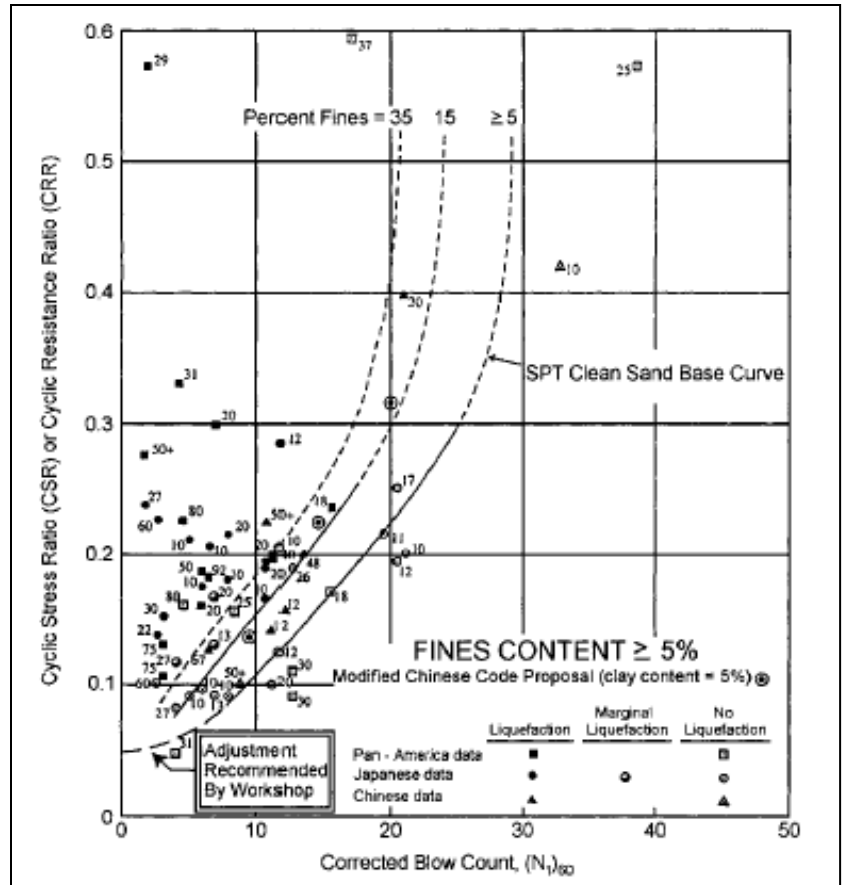

FIG. 2. SPT Clean-Sand Base Curve for Magnitude 7.5 Earthquakes with Data from Liquefaction Case Histories (Modified from Seed et al. 1985)

Magnitude Scaling Factors (MSF)

Magnitude	Idriss (1995)	Andrus and Stokoe (1997)
5.5	2.20	2.8
6.0	1.76	2.1
6.5	1.44	1.6
7.0	1.19	1.25
7.5	1.0	1.0

Attachment 1

"Simplified" Seed Procedure (2001) for Calculation of Liquefaction Potential

Note: Figure 2 and Figure 15 extracted from "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils" by T.L. Youd and I. M. Idriss from the Journal of Geotechnical and Geoenvironmental Engineering, April 2001. Also, equation to determine all factors (e.g., MSF, are present in that document.

TO: Craig H. Bensen (University of Wisconsin – Madison)
Dinesh Gupta (U.S. Department of Energy)
Edward F. Johnson (U.S. Department of Energy, Contractor)

FROM: Nick Geibel (U.S. Army Corps of Engineers, Geology Section)
Jennifer Grimm (U.S. Army Corps of Engineers, Geology Section)

SUBJECT: Olmsted Lock and Dam synopsis of seismic evaluation history.

DATE: 7 July 2008

1. (1988) The primary purpose of the seismic evaluation appeared to be to support the proper design of structures associated with the Olmsted Lock and Dam project and not liquefaction potential of site soils. Used deterministic approach to obtain earthquake magnitude and resultant peak horizontal ground acceleration (PHGA) for operating basis earthquake (OBE) and maximum credible earthquake (MCE).
   - OBE: Magnitude 6 earthquake within 25 km of project resulting in a 0.44 g PHGA.
   - MCE: Magnitude 8 earthquake within 45 km of project (New Madrid seismic zone) resulting in a 1.12 g PHGA.

2. (1995) U.S. Army Corps of Engineers (USACE) changes definitions of OBE and MCE.
   - OBE: Ground motions that have a 50% chance of being exceeded during a 100 year service life (i.e., ground motions with a 144 year return period). The OBE is characterized as a probabilistic event.
   - MCE: Revised guidance called for the use of a maximum design earthquake (MDE) to be used in place of the MCE if the structure evaluated is not critical in nature, otherwise the MDE and MCE are equal. The MDE is the maximum level of ground motion for which a structure is designed or evaluated. The associated performance requirement is that the structure perform without catastrophic failure, such as uncontrolled release of a reservoir, although severe damage or economic loss may be tolerated. For critical features, the MDE is the same as the MCE. For all other features, the MDE shall be selected as a lesser earthquake than the MCE which provides economical designs meeting appropriate safety standards. The MDE can be characterized as a deterministic or probabilistic event.

3. (1996) Ground motion study was revised to obtain the OBE and MDE earthquakes and their resultant PHGAs due to the revision of USACE guidance providing the OBE to be characterized via probabilistic seismic hazard analysis (PSHA) methods. The study included:
   - Geologic, tectonic, and seismicity data collection, compilation, and evaluation to determine seismic zones and their postulated earthquake magnitudes.

- PSHA was utilized to determine the hard rock response spectra, with 5% damping, of the OBE and MDE, for the top of the bedrock (limestone). To develop the design ground motion (PHGAs) from OBE and MDE events for the site, the OBE and MDE events along with a site soil profile (shear-wave velocity, density, Poisson's ratio) were input into the computer program SHAKE. Curves representing PHGAs at various response spectra were determined for the OBE and MDE events (structural engineers determine what period/PHGA is appropriate).

4. (1998) Additional geotechnical information (6 borings) indicates that lower portions of the McNairy formation (overlies the bedrock limestone) contains moderately hard to hard shaley limestone rather than the unconsolidated materials originally envisioned. Therefore, the site response analysis evaluations for the OBE and MDE were rerun accounting for the upward revised shear-wave velocity of the McNairy formation. The shear-wave velocity for the McNairy formation was estimated at 2,500 ft/sec and the velocity of the limestone bedrock was estimated at 8,000 ft/sec. Reporting indicated that cross-hole geophysical techniques were employed to determine the shear-wave velocity of the soil profile at two sites associated with the Olmsted Lock and Dam project – unfortunately specific detail respective to the exact number and depths of the cross-hole geophysical testing sites efforts was not available. (The maximum PHGAs for the OBE and MDE response spectra were estimated at 0.56 g and 2.5 g, respectively. However, it should be noted that structural engineers will select the ultimate PHGAs to be used in the analysis of structures and may not be the same as the maximum PHGAs stated above.) Final design memorandum established in 1999 to present some information and criteria for the design of the structures for Olmsted Lock and Dam project.