Lessons Learned from the TVA Kingston Dredge Cell Containment Facility Failure
TDEC Advisory Board Recommendations for Safe Performance

November 30, 2009

Introduction

The Tennessee Valley Authority (TVA) Kingston coal fired electric generation plant (KINGSTON) is located on the Watts Bar reservoir, at the confluence of the Clinch and Emory rivers, near Kingston, Tennessee. Construction of the fossil plant began in 1951, and operations began in 1954. The fossil plant was constructed in a flood plain between Swan Pond Creek and the Emory River. The Kingston plant, along with other TVA plants, utilizes wet process coal waste material storage. The extent and location of the Kingston processing facilities (dredge cell) evolved in size and construction over the years from their initial beginnings as a limited height storage cell to a structure nearly 100 feet in height above the slough as in place on December 22, 2008.

The Kingston dredge cell containment facility failed on December 22, 2008. An Advisory Board has been assembled at the request of the Tennessee Department of Environment and Conservation (TDEC) in response to the failure. The failure breached through the north and central portions of dredge cell 2, including the north containment dike, resulting in the release of more than 5.4 million cubic yards of coal ash. Ash flowed onto private property, TVA property, and into the Emory River. The ash flow damaged several structures and filled several TVA-owned sloughs with ash debris and embankment material.

The Kingston dredge cell was constructed in the flood plain, as the plant began operations, with portions of its containment structure constructed in the backwater slough of Swan Pond, which is an old oxbow of the Emory River. As with the location and extents of the Kingston dredge cell, the methods of construction for the embankments of the Kingston dredge cell have also evolved over time. The initial containment was a conventional soil (clay) embankment. In later years, the construction evolved to methods seen in mining and other waste material storage industry practices, typically termed as upstream staged construction. In this type of construction, a limited height of the ultimate

containment structure is constructed, the waste byproduct is impounded behind the partial height structure and the next phase of the containment structure is added atop the original containment embankment with the remainder of the added upstream embankment founded upon the waste byproduct that had been placed behind the previous containment embankment. The process is repeated until the ultimate design height is attained. The failure occurred through this construction.

TDEC Advisory Board

After the Kingston dredge cell failure, James H. Fyke, TDEC Commissioner, with the concurrence of the Governor of the State of Tennessee, issued an order requiring TVA to perform a comprehensive evaluation of all of TVA's coal ash impoundments located within the State of Tennessee. TVA was requested to submit to TDEC all existing studies, reports and memoranda that were potentially relevant to explaining or analyzing the cause of the Kingston failure. The order authorized creation of an independent Advisory Board to aid the State in its evaluations. Formed in February 2009, the independent Advisory Board was charged with assessing the scope and methodology of TVA's evaluation of the Kingston dredge cell failure and their other coal ash facilities. The Advisory Board is comprised of individuals with diverse engineering and regulatory capabilities. The list of members and their associations are presented at the end of this report.

Advisory Board Guiding Principle

The primary guiding principle of the Advisory Board is to support TDEC and the public through evaluation or general consideration of existing safety procedures, engineering design guidelines, and the assurance of proper construction compliance for structures that place the public at personal and economic risk.

In performing its duty, the Advisory Board has reviewed the investigations of the Kingston failure evaluations and the initial (Phase 1) evaluations of the other TVA coal combustion waste facilities to develop an understanding of the methods utilized by TVA in determining the causes of failure at Kingston and the conditions at the other plants. Determination of the exact cause of the Kingston failure is not the responsibility of the Advisory Board.

Advisory Board Approach

The Advisory Board has reviewed available information, attended TVA briefings, performed site visits and assessed TVA processes to establish lessons learned from the Kingston failure and developed recommendations for safety at other plants. Many documents were reviewed and considered in the evaluation by the Advisory Board. These include, but are not limited to:

- Documents provided to TDEC by TVA
- TVA Kingston Fossil Plant Annual Ash Pond Dike Stability Inspection, January 12, 2009, TVA
- Kingston Fossil Plant Ash Slide Interim Report, June 12, 2009, and the Review of the Kingston Fossil Plant Ash Spill Root Cause Study and Observations about Ash Management, July 23, 2009, the TVA Office of the Inspector General
- The deposition of the Kingston inspector In The Matter of Mary Margaret Blanchard, et al. v. Tennessee Valley Authority, June 17, 2009, Vowell and Jennings, Inc.
- Report of Phase I Facility Assessments, Various Locations, Tennessee, June 24, 2009, Stantec
- Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008, June 25, 2009, updated August 5, 2009, AECOM

- Peer Review of the AECOM Root Cause Analysis of TVA Kingston Dredge Pond Failure on December 22, 2008, Marshall Miller and Associates, Inc., July 2009

Advisory Board activity has primarily focused on the Kingston failure investigations with limited review of the Phase I investigations of the other facilities. The information gained from the review of the Kingston failure is applicable at other facilities. The Advisory Board members have had several opportunities during meetings, presentations and site visits to express their opinions and concerns to TVA and their contractors about inspections, stability analysis, and management oversight with some of those comments having been utilized in the evaluations, analyses and management processes.

In evaluating the TVA investigations performed by Stantec of the other facilities, the Advisory Board has performed overview evaluations of the Stantec Phase I investigations and tasked The Benham Companies (Benham) with a more detailed review of the Phase I investigations and follow-up investigations of issues TVA identified in the Phase I investigations. Benham will confirm quality assurance, perform laboratory testing and develop a separate report of findings. Currently, Benham's work is awaiting final TVA Phase II testing for the New Johnsonville plant containment and its associated analysis results before finalizing the quality assurance testing and performing an assessment of the TVA results. The New Johnsonville plant has been established as the quality control review project due to some similarity to Kingston and because it was identified in the Phase I investigation report as one of the most critical plants. After Benham reports their results, the Advisory Board will present a subsequent document with a separate assessment.

Advisory Board Principle Finding

The Advisory Board has determined that the primary emphasis for TDEC and associated federal regulating agencies should be on improved life-cycle design requirements and related operational procedures for Coal Combustion Waste facilities. The Advisory Board emphasizes the need to protect the public from failure of Coal Combustion Waste facilities in Tennessee, throughout the facilities' lives, by employing (1) thorough engineering design principles; (2) effective engineering safety monitoring, inspection, and follow-up maintenance; and (3) an engineering philosophy and long-term plan that can be safely followed and modified, as needed, as these types of facilities evolve. The needed regulating policy may be implemented by developing and publishing stated, thorough design requirements for staged construction. It may be more appropriate that phased construction utilizing embankment materials without documented structural and drainage properties not be allowed.

Lack of Engineering Principles – TVA Kingston

The Advisory Board is in complete agreement with other published reports regarding one fundamental, critical deficiency at the TVA Kingston dredge cell: there was an apparent lack of understanding or consideration of the evolutionary process of the construction at the TVA Kingston plant. Additionally, there was no on-going, consistent method of design evaluation, documentation and communication to manage the evolutionary process. TVA retained at the Kingston site a "living" set of drawings that reflected changes in concept and documented actual construction. Unfortunately, the documents did not correctly or adequately consider variables and inconsistencies in the assumed design. Design assumptions were neither checked nor updated, and it does not appear the conditions of documented weaknesses in the foundation were adequately considered in design and construction modifications. The evolution of the

Kingston ash storage structure lacked design continuity and effective structural stability oversight by TVA management throughout its history.

TDEC and applicable federal regulatory agencies should focus on the need for guidelines or regulations that will improve life-cycle design requirements and related operational procedures for coal combustion waste (CCW) facilities and other containment structures with similar characteristics. Such guidelines or regulations should be of such nature as to require effective management oversight and thorough engineering design philosophy based on a technical understanding of the underlying foundation conditions, materials, forces, and construction for the entire life of a given structure. The analyses should be continuously revisited and modified to reflect monitoring data and the as-built conditions as the structure is constructed over time.

Analysis for a given structure should be based upon a clear understanding of the type of structure being designed, the structure's foundation, the applied loads and the materials involved. It is apparent that the types of materials used in the construction of the Kingston dredge cell were assumed to perform similarly to conventional soil materials, but the actual material properties were not clearly understood. The underlying assumptions and engineering experience of the engineers and construction staff charged with managing the Kingston dredge cell design and construction are not thoroughly documented in the TVA design documents. However, review of the designs and constructions utilized reveal that the designers believed or assumed the materials utilized had engineering properties similar in nature to conventional soils. In actuality, the sluiced fly ash materials do not behave in a manner consistent with conventional clay and silt embankment construction. Loosely deposited sluiced fly ash, without the benefit of secondary consolidation, has been shown to perform in a manner more consistent with that of unconsolidated loose sand and silt. An understanding of the materials used in engineered construction along with reasonable factors of

safety to account for variations in construction, materials and reliability of assumptions is an inherent requirement of engineering design practice.

The responsibility to understand or develop an understanding of the design and material parameters is a part of the standard of care expected of a practicing engineer or engineering organization. Standard of care is vital to the design of any structure and must be adequately defined for any engineer engaged in professional practice. Standard of care for a Professional Engineer can be summarily defined as that quality of service ordinarily provided by other normally competent engineers of good standing in the field of engineering, providing similar services in the same locale and under the same circumstances. It is clear to the Advisory Board that the quality of engineering design, construction, inspection and maintenance provided throughout the life of the Kingston plant did not incorporate the standard of care and the understanding required for this type of structure.

Primary Issues – TVA Kingston

Based on the Advisory Board review, the following issues have been identified as areas where policies and procedures should be improved:

1. Inspection Process/Inspector Qualifications
2. Emergency Response
3. Operation and Maintenance
4. Engineering Analysis

Although the issues are all considered to have equal levels of value and importance, the areas of emergency response, inspection and operation are reliant upon the underlying engineering design and analysis.

1. Inspection Process/Inspector Qualifications

There are varying types and levels of inspections needed for embankment structures. The need and type is dependent upon the reliability of the design, quality of construction, the stage of its life and current performance of the structure. TVA performed annual inspections of the dredge cell structures and other visual observations more frequently. If the inspections were based on a clear plan or understanding of the design, the Advisory Board did not identify such guidance in the documents reviewed.

The final annual internal inspection report for the Kingston dredge cell was dated January 12, 2009, following the December 2008 failure. The field inspection had been performed October 20, 2008, two months prior to failure. The inspection was performed by three TVA engineers. The report was drafted by the newest engineer, who was present at the inspection but had not performed similar inspections previously and had received no training in the execution of such inspections. The October fly ash structure inspection was considered to be a training inspection for him.

The need to bring new and less experienced staff into the process over time is recognized. In doing so, training and exposure of the new personnel will be necessary. Nevertheless, preparation of evaluation reports and procedures has to remain under the supervision and control of properly trained and experienced personnel. Inspectors should receive adequate training and follow established guidelines throughout the inspection process. The training and background of inspectors should be validated. Continuity of inspection personnel should be maintained from one inspection to the next. The inspection should be performed to the same standard of performance as federal guidelines require for regulated dam structures and certification should be submitted to TDEC stating that individual structures have passed inspection criteria. CCW facilities which are subject to removal (dredging) activities should also report depth and location of

dredging as part of the inspection procedure to determine if anticipated settlement or unanticipated movement has occurred.

Construction and phased construction reporting require development of a construction monitoring plan. The plan should include specific requirements for the verification of intended design requirements and should include construction observation documentation. Until such time as the construction is determined to be completed and the closure accepted, staged construction monitoring should continue as would any major structure construction observation plan.

2. Emergency Response

Emergency planning and preparedness are critical aspects for the safe management and operation of containment structures including CCW structures. Emergency procedures were in place for Kingston which were reasonably effective. However, according to the Kingston Fossil Ash Slide Interim Report, June 12, 2009, Office of the Inspector General, TVA had unfortunately not implemented the National Incident Management System (NIMS), as required by the Homeland Security Presidential Directive (HSPD)-5, which hampered communications and delayed certain emergency response actions following the spill. TVA should implement NIMS training and changes to the Emergency Response Plans (ERP's) to improve communications with other agencies should TVA encounter another emergency situation. The Board understands that TVA is in the process of issuing final emergency plans and that the plans are being coordinated with NIMS. Also, TVA should add emergency management personnel and complete comprehensive hazardous analysis and risk assessment for all TVA owned and operated facilities as recommended by the Inspector General's report dated June 12, 2009. Because of the high risk to life, property or environmental damage from potential failure, TDEC should review their requirements for similarly permitted facilities and associated risk to determine commensurate levels of emergency planning and preparedness. The Board

believes the ability to predict risk to life and property from CCW structures to be problematic as there are not any applicable predictive modeling tools for wet fly ash flow that the Board is aware of. Thus, TDEC should develop requirements for preparedness plans that consider a boundary for potentially affected topographic features based on mud flow and flood wave propagation to develop requirements for CCW storage that will minimize any life threatening effects due to failure. The requirements should be applied, at a minimum to any CCW structure over 25 feet in height above the adjacent ground and lower if adjacent risks are identified.

3. Operation and Maintenance

Assumptions as to loads, rates of loading and seepage control are critical to the design, construction, evaluation and operation of soil and soil-like embankment structures. The allowable rate of loading (dredging) as anticipated based on design conditions, was not considered in the design or specified as part of the permit criteria at Kingston. The rate of loading should be specified as part of the permitting process, properly monitored, and adequately documented. Construction Quality Assurance should be part of the operations plan such that review and approval by qualified personnel is performed prior to waste placement. The removal of material from impoundments should only be performed in accordance with approved operating procedures.

4. Engineering Analysis

The evolutionary construction of the Kingston dredge cell was not initially considered or adequately evaluated throughout the life of the facility. Structural stability oversight was lacking. This is evidenced by the lack of stability analyses performed for the structure at critical locations and various stages of construction. Analyses completed for seepage and structural stability were incomplete and did not consider the comprehensive stability for the various and

most critical sections of the structure. Analyses performed by TVA addressed events and locations associated with observations of failure or near-failure conditions and did not utilize such events as impetus to assess their understanding of the full structure. Analyses did not adequately address the existence or properties of foundation materials, stored CCW material as an integral portion of the supporting containment structure, or long-term retained pore water pressures associated with ash materials and their interaction with their foundations and adjacent embankments.

The initial and evolutionary design must be based on a comprehensive site assessment that considers all materials to be utilized as well as the evolutionary construction/engineering process. A long-term plan for the facility needs to be initially established, evaluated during construction to verify compliance and performance, and then re-evaluated with each new construction/phase. These re-evaluations should be peer reviewed and documented for review by TDEC or other appropriate regulators to ensure that calculations were performed in accordance with acceptable criteria and by a qualified engineer to the standard of care expected. CCW impoundments, if allowed, should require a design to meet ground water protection standards, material evaluation requirements, static and seismic stability requirements for construction, long term and extreme conditions, construction quality control, and closure/post closure maintenance. Conservative physical properties for randomly placed, sluiced fly ash must be developed and applied in designs for CCW facilities utilizing fly ash as a part of the wet or dry impoundment structure. Existing CCW facilities that are to be closed should have a site-specific closure plan which evaluates materials, determines current and closed stability, and provides for long term monitoring/maintenance. The general finding of the Advisory Board is that use of elevated dredge cells by means of upstream staged construction for coal ash is neither desirable nor recommended due to the need for specialized understanding of the material performance. Elevated storage by means of independent containment can be

safely utilized when properly designed and constructed utilizing acceptable engineering practices and appropriate materials.

All allowed impoundments should have a comprehensive site assessment of conditions, intended materials, and anticipated designs. Structural evaluation is reliant upon an understanding of the materials, their properties, and their performance under the various loads to which the structure is subjected. The analysis and construction at the Kingston dredge cell relied upon assumptions of density, strength, and stability of sluiced fly ash which, in turn, provided support for the engineered fills of fly ash and bottom ash that were intended to be the primary containment. Fly ash has unique material properties and assumptions about those properties, based on conventional soils that do not perform in the same manner, are not sufficient for use in engineering analysis. Extensive geotechnical analysis of fly ash properties is necessary to facilitate reliable use in engineered construction.

The Advisory Board recognizes that fly ash can be safely utilized as an engineering material when properly understood, considered, and constructed. However, it may be prudent to consider requiring that elevated CCW storage be allowed only within a designed primary containment structure that does not rely upon upstream staged construction techniques that utilize non-engineered sluiced fill as a portion of the staged engineered embankment construction. If staged upstream construction methods are allowed for CCW or similar facilities, appropriate analyses and treatment of staged construction foundations that account for the material properties of the waste products should be required.

Evaluation of other TVA Facilities

Inspection, Emergency Response, Operation, and Engineering Analysis represent the areas of major concern in evaluating and permitting existing or future CCW facilities. They also represent the deficient design and construction

issues relative to the performance of TVA at the Kingston facility. The same issues need to be considered at other existing TVA facilities in order to provide the required level of safety. Preliminary Phase I investigations developed by TVA and reviewed by the Advisory Board indicate that designs utilizing staged fly ash embankment construction do not exist at all sites. Some of the underlying issues, however, do exist at other TVA coal fired plants. TVA, through its consultants, is performing the necessary evaluations and taking remedial actions. TDEC has asked the Advisory Board to perform limited level evaluations of the work at other TVA facilities in the State of Tennessee and those evaluations are on-going. Final findings will be issued in a separate assessment after receipt of the supplemental TVA report and the associated improvement plans.

Root Cause Analysis – TVA Kingston

The Root Cause Analysis report (RCA), initially published by AECOM on June 25, 2009, and updated on August 5, 2009, considered several possible failure modes for the Kingston dredge cell failure. These are listed below.

1. Earthquake Shaking and other vibration sources
2. Excess Rainfall
3. Rapid Reservoir Drawdown
4. Karstic Limestone Sinkhole or other Bedrock Instability
5. Artesian Groundwater Instability
6. Shallow Dike Instability due to seepage outbreak on slopes or a piping failure
7. Intermediate Depth Instability of Dredge Cell or its Dikes
8. Deep Seated Instability of Dredge Cell through Ash only
9. Increased Filling Rates into Dredge Cells
10. Deep Seated Instability along a Weak Foundation Layer
11. Static Liquefaction
12. Progressive Failure of Fill after Initial Cell 2 and Dike C Breach

Based on the initial evaluation, AECOM concluded four factors concurrently contributed to the rapid failure of the dredge cell and studied those in more depth. These include:

1. Fill Geometry and Setbacks
2. Increased Loads Due to Higher Fill
3. Unusually Weak Silt/Ash Slime Foundation
4. Hydraulically Placed Loose Wet Ash

AECOM determined that the dredge cell was on the verge of a deep seated failure at a critical stability condition with no visible pre-failure signs of distress. AECOM noted that a weak foundation interface existed in certain areas overlying an already weak foundation as a result of ash sluicing prior to construction of the outer containment dike. This weak foundation interface layer was very deep, less than six inches thick, and was discovered through extensive undisturbed material sampling investigations.

The Advisory Board has observed the processes and reviewed the data, evaluations, and conclusion of AECOM's work; the Advisory Board does not agree or disagree with their conclusions. The Advisory Board finds that AECOM performed an extremely thorough and qualified technical review of the Kingston failure that considered potential failure modes either directly by means of forensic investigation or indirectly by means of associated analyses. While the Advisory Board concurs that the weak foundation interface layer likely did contribute to the failure that occurred, the stability of the Kingston dredge cells were at a critical state of failure regardless of the presence of the emphasized layer of weak foundation material. The lack of engineering design for the raising of the cells, the inadequately understood material properties, pore pressure dissipation properties and material consolidation mechanisms of the ash, the methods of placement of the ash, the staged upstream construction, and the dredging

activities all contributed to the condition of the pre-failure structure. Any combination of the many failure modes investigated by AECOM could have and would have ultimately resulted in a failure at the Kingston site. Failure modes are being investigated at other TVA sites that used different methods of construction for similar methods of storage for CCW. Other sites should not be assumed safe simply because a specific layer of weak foundation material is not present. Each site should receive a site-specific evaluation of its materials, design, operations, and possible failure modes to assess its safety and associated closure plan.

Advisory Board Recommendations

TVA must complete structural integrity evaluations of all coal ash storage facilities. While the Stantec investigation of the other TVA coal ash storage facilities is ongoing, TVA should provide site-specific quarterly reports of activity and analysis to TDEC.

TVA needs to employ proper expertise in the management, design, construction and evaluation of their wet ash storage facilities. Wet coal ash storage facilities should require the same accountability as dams. Although the necessary expertise could be attained through additional staffing or through external consulting, knowledgeable expertise is already available within TVA. TVA should move management of wet ash storage facilities under the supervision of the TVA Dam Safety group. The Advisory Board strongly believes that fragmented organizational oversight and responsibility with an inadequate comprehension of the safety risks for these facilities led to inadequate technical oversight.

All reports and analyses for TVA wet ash storage facilities and TVA dry ash storage facilities, or landfills, located within Tennessee should be submitted to TDEC. This includes reports and analyses prepared by consultants that may or may not be directly applicable to permits. Examples include any stability analyses that are performed, geotechnical investigations and reports,

recommendations for further analysis, in-house and outside inspection reports, verifications, etc.

The facility owner must provide calculations that are signed and sealed by a Registered Professional Engineer, registered in the State of Tennessee.

Through the permitting process, a facility owner should prepare a detailed inspection regimen that will be effective for the active phase of construction. Another inspection regimen should be prepared for use after construction is complete and the facility is placed in final operation or closure. If phased construction is allowed and utilized, the inspection regimen must be recognized and developed for construction conditions. Inspectors shall be Registered Professional Engineers that have qualified training and experience in dam safety and associated construction work. A comprehensive design plan shall be submitted to TDEC with checkpoints planned at different phases for assessing structural and seepage force stability performance. If after closure or other stage of construction, the facility returns to a construction or operation condition, at a minimum, quarterly inspections should be performed that consist of establishing monuments and checking their coordinates to determine if movement or settlement is in accordance with expectations. Resolution of inspection recommendations should be checked by TDEC for inclusion in subsequent reports. Interim stability analyses should be performed for every ten to twenty feet of additional storage for wet or dry storage.

An independent evaluation Board consisting of two to three geotechnical, hydraulic and dam safety experts should be established to provide expert oversight during design, construction and closure plan development. The facility owner would be responsible for hiring and reimbursing the required Board members. A system similar to that used by the Federal Energy Regulatory Commission (FERC) could serve as an organizational model. As with FERC procedures, TDEC would retain approval rights for the board members.

The Advisory Board recommends that staged upstream construction not be used with CCW facilities. Wet storage of coal ash is acceptable if a containment structure is constructed. This containment structure (dam) should be designed, constructed, inspected, operated, maintained and regulated as a dam according to federal guidelines. Provisions should be made to ensure that any dredging activities do not disturb the toes of the dam, which would negatively impact the stability of the containment structure.

Performance criteria should be established by TDEC consisting of items that are of a general nature and would apply to multiple types of impoundments. These criteria could be in a checklist form. This would be a valuable reference tool for TDEC for use in permit approval.

The Tennessee Safe Dams Act of 1973 should be amended to eliminate the exemptions for farm ponds, wastewater impoundment barriers, and diversion weirs. All dams with high or significant hazard should have regulations applied regarding safety and stability.

Advisory Board members include Dr. Bruce Tschantz (Professor Emeritus Civil and Environmental Engineering, University of Tennessee, Knoxville), P.E, Lyle Bentley (Chief, Safe Dams Section, TDEC Division of Water Supply), P.E., Richard Kramer (Civil Engineer, Benham Consultants), P.E., Karrie Jo Shell (Environmental Engineer, Environmental Protection Agency – Region IV), P.E., Saya Qualls (TDEC Division of Water Pollution Control), P.E., Glen Pugh (TDEC Division of Solid Waste Management), and Steve Jacoby (Structural Engineer, Benham Consultants), P.E

The Board appreciates the opportunity to have been of service in the evaluation of this issue. The Board will present its opinions on the continuing work at the other TVA facilities upon receipt of the completed Benham evaluation report.