APPENDIX D
Risk and Mitigation of Accidents at Proposed Regenesys™ Facility

Background

In the development of the first Regenesys™ facility in the United Kingdom (UK), a thorough plant hazard identification and assessment analysis was undertaken using hazard and operability analysis (HAZOP). All design and operation documents (process and instrumentation diagrams, process flow diagrams, material flow diagrams and operating procedures, and control philosophies) were examined by a group of specialists drawn from:

- Innogy technical development group.
- Innogy operation and evaluation group.
- Plant engineering and construction contractors.

Abnormal causes and adverse consequences for possible deviations from normal operation that could arise were identified for each unit and each plant process line. The formal HAZOP was used at each stage of the plant life-cycle (concept design, basic design, detailed design, construction, commissioning, operation and decommissioning) to assess potential hazard risks. HAZOPs were used at the earliest possible stage in the process design so that safety formed an integral part of the design iteration process.

The "risk" methodology adopted involved the following steps:

- Hazard identification.
- Estimate of the frequency of an event.
- Consequence analysis.
- Risk calculation and assessment.

Overall risks for each event were determined from a fault tree event analysis (FTA) and assessment of consequences by modeling when appropriate; (for example, dispersion of gas from the incident site in various meteorological conditions).

The environmental impact of all releases from the Regenesys™ plant was assessed as part of the design development process. This study involved determining release rates and quantities, and carrying out dispersion modeling to determine concentrations in the environment. Comparison was then made with relevant environmental quality standards (EQSs) or environmental assessment levels (EALs) to determine significance of the release.

To determine the risk of a major accident scenario causing serious damage to the environment, the following steps were considered in detail:

- Identification of the source of the risk.
- Development of the release scenarios.
- Determination of the probabilities of a release into the environment.
- Determination of the consequence of each release and whether it would lead to a major accident.
- Determination of the risk and assessing the acceptability of this risk.

Innogy found that the events which could cause the release of electrolyte would most likely be the breakdown of a module inside the process building or the loss of electrolyte during tanker unloading. In the latter case, the sodium bromide would not be in the charged state and therefore would not impact the atmospheric environment.

The TVA Regenesys™ plant will be a near duplicate of the UK plant and incorporates HAZOP knowledge gained and lessons learned from the UK plant. In order to assess whether any additional risks have been introduced as a result of siting the plant in Mississippi, an internal review of the design was carried out by TVA specialists.

Current Design

Complete HAZOPs and design reviews have also been performed to ensure the US plant design takes into account such risks and is modified to mitigate these risks as far as is reasonably practicable. These reviews are in addition to the previous work performed for the UK plant. The TVA plant will be designed so that it fully complies with all US codes and standards. These reviews will involve specialists drawn from TVA, Innogy the architectural engineer, and the construction contractor.

During operation, when the sodium bromide electrolyte is in a charged state, the process does contain bromine gas (approximately 300 lb) in the headspace above the sodium bromide electrolyte. Bromine is classified as an extremely hazardous substance. The presence of bromine dictates compliance with the General Duty Clause of the Clean Air Act section 112(r) for this facility.

Specifically, Section 112(r)(1) states:

> (r) Prevention of Accidental Releases
> (1) Purpose and General Duty - It shall be the objective of the regulations and programs authorized under this subsection to prevent the accidental release and to minimize the consequences of any such release of any substance listed pursuant to paragraph (3) or any other extremely hazardous substance. The owners and operators of stationary sources producing, processing, handling or storing such substances have a general duty, in the same manner and to the same extent as section 654, title 29 of the United States Code, to identify hazards which may result from such releases using appropriate hazard assessment techniques, to design and maintain a safe facility taking such steps as are necessary to prevent releases, and to minimize the consequences of accidental releases which do occur.

The general duty clause has been in effect and enforceable since November 15, 1990. It applies to any facility where extremely hazardous substances are present. The general duty clause is a performance based authority recognizing that owners and operators have primary responsibility in the prevention of chemical accidents.

The general duty clause imposes the following primary obligations on owners and operators of stationary sources.

- Identification of hazards which may result from accidental releases using appropriate hazard assessment techniques.
- Design and maintain a safe facility taking such steps as are necessary to prevent releases.
- Minimization of the consequences of accidental releases which occur.

Owners and operators should also be prepared to minimize effects on the public and the environment by identifying at-risk receptors in the event of maximum possible release and other probable releases as may be identified in the hazard analysis/review. Although the general duty clause does not specify how an owner/operator should identify hazards, when concluded, the hazard assessment should result in the following information.

- Hazards associated with extremely hazardous substance and the process.
- Potential release scenarios developed from site specific hazard analysis/review and facility/industry historical data.
- Consequences of release in each case.

Hazard Identification

Sodium Polysulfide

Because of its high pH and corrosivity, care must be taken to keep sodium polysulfide solution away from water supplies.

Sodium Bromide

For the purpose of establishing occupational exposures, and for emergency planning, air concentration levels have been established for bromine. The short-term (I5-minute) exposure level is 2 mg/m^3, and the 8-hr exposure threshold is 0.7 mg/m^3. EPA's *Offsite Consequence Analysis Guidance* (1996) lists the toxic endpoint concentration for bromine as 0.0065 mg/L (6.5 mg/m^3). Toxic endpoint concentration for a compound is the maximum airborne concentration below which it is believed individuals could be exposed for one hour without experiencing or developing irreversible or other serious health effects that could impair the individual's ability to take protective action. The primary risk from the sodium bromide solution is the release of bromine when it is in its charged state. However, the process is charging and discharging throughout the day, so the electrolyte does not remain in its fully charged state at all times. When the Regenesys™ system is in the charging mode, sodium ions are transferred from sodium bromide electrolyte to sodium polysulfide electrolyte through membranes in the modules. When fully charged, bromide is complexed as sodium tribromide ($NaBr_3$) and bromine exerts a vapor pressure above the solution. The volume of bromine that is contained in the tank headspace above the electrolyte could be released in the event of a significant rupture of the inner and outer tank walls. Additional bromine gas would evolve if the electrolyte remained exposed with no control measures in place.

Events that could cause a catastrophic failure of the double-walled sodium bromide electrolyte tanks and the maximum possible release of bromine gas are discussed below.

Scenario A, Electrolyte Tank Failures

Evaluation of Aircraft Crash Risk

Mountain City, Tennessee Regenesys™ Sites

To evaluate the probability of aircraft collision, the risk was calculated using the US Nuclear Regulatory Commission's Standard review plan section 3.5.1.6 Aircraft Hazards for nuclear plants. Factors used in calculating the risk included the use of the runway which is equal to 2,000 events annually. These events include takeoff and landing approaches, as well as passes made in a holding pattern.

Plant impact area, including skid area, selected for this evaluation was a 200- by 400-foot rectangle around exposed sides of the sodium-bromide tank. The area of this rectangle in square miles is 0.00287. The diagram below shows a layout of the plant with the sodium-bromide tank identified.

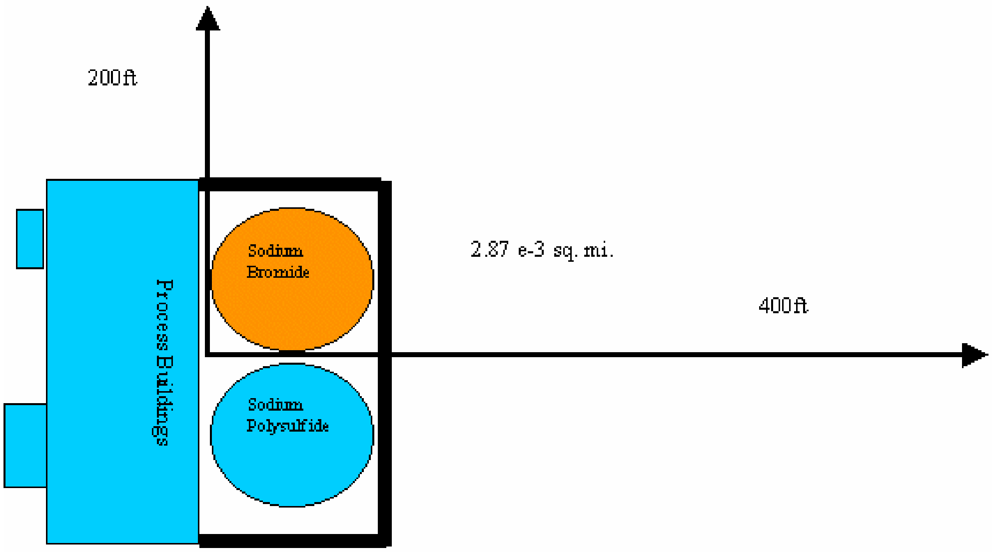

Figure D-1. Impact Area for Aircraft Crash

The probability calculation calls for use of a factor selected based on the distance of the site from the runway and on the type of facility the site is near, such as, a US Carrier, a General Aviation facility, a US Navy/Marine Corps facility, or a US Air Force facility. The Shouns Substation site and the Mountain City Industrial Complex are approximately 1.7 miles from the Johnson County Airport. The factor for both sites found under the General Aviation column, is a 15 x 10^{-8} probability of a crash per square mile per aircraft movement.

$$\text{ANNUAL PROBABILITY} = \frac{(2{,}000\ movements)\times(0.00287\ mi^2)\times(15\times10^{-8})}{year\times mi^2\times movements}$$

$= 8.61 \text{ X } 10^{-7}$ per year.

These two sites would represent the worst case since the Johnson County Industrial Park site is further away from the airport (approximately 4 miles). The probability of an aircraft crash at this site would therefore be lower, based on the calculation method above.

Oliver Springs, Tennessee Sites

The Braden Field site is the obvious worst case when considering the potential for aircraft crashes among the proposed Oliver Springs sites. Using a conservative estimate of 2,000 movements per year and a factor of 84 x 10^{-8}, the probability is calculated to be 4.8 x 10^{-6} per year.

The probability of this event is low enough to eliminate it as a means of maximum possible release.

Evaluation of Tornado Risk

Oliver Springs, Tennessee

There are excellent records on occurrence of tornadoes in populated areas of the United States. One source used for nuclear plant siting applications is "Tornado Climatology of the Contiguous United States" (NRC, 1986). To determine the probability of a tornado occurring in the vicinity of Oliver Springs, a study area containing the proposed plant sites was defined as a box of one degree latitude by one degree longitude (84°W to 85°W by 36°N to 37°N) or a square with sides about 62 miles in length (approximately 3,836 square miles).

The average tornado path affects an area of 2.28 square miles (Thom, 1963). As an example, this would be equivalent to a tornado with a path width of 0.25 miles and a travel distance of 11.28 miles (0.25 miles x 11.28 miles = 2.28 square miles). A total of 32 tornadoes occurred in the study area between 1954 and 1983, resulting in a tornado frequency of 1.07 tornadoes per year (53 tornadoes/30 years = 1.77). The annual probability of a particular site in this study area being affected may be calculated as follows:

ANNUAL PROBABILITY = $\dfrac{(1.07\ tornadoes/year)\times(2.82 squaremilesaffected/tornado)}{(3{,}836 squaremilesstudyarea)}$
= 0.0008 per year.

That is to say, there is a 0.08 percent chance, each year, of a tornado affecting a particular site in the study area.

Risk can also be expressed by calculating a recurrence interval or how often, on average, a tornado may affect a particular site.

RECURRENCE INTERVAL = 1/(0.0008 per year) ~ 1271 years.

Therefore, a tornado would be expected to affect a site in the study area, such as the Regenesys™ facility, once every 1271 years.

Mountain City, TN

To determine the probability of a tornado occurring in the vicinity of Mountain City, a study area containing the proposed plant sites was defined as a box of one degree latitude by one degree longitude (81°W to 82°W by 36°N to 37°N). The annual probability of a particular site in this study area being affected may be calculated as follows:

ANNUAL PROBABILITY = $\dfrac{(1.07\ tornadoes/year)\times(2.82 squaremilesaffected/tornado)}{(3{,}836 squaremilesstudyarea)}$
= 0.0003 per year.

That is to say, there is a 0.03 percent chance, each year, of a tornado affecting a particular site in the study area.

Risk can also be expressed by calculating a recurrence interval or how often, on average, a tornado may affect a particular site.

RECURRENCE INTERVAL = 1/(0.0003 per year) ~ 2890 years.

It should also be noted that, damage to, or failure of the tanks may or may not be caused simply by the occurrence of a tornado in the study area. Additional probabilities must be considered for events that could be produced by the tornado and be more likely to cause sufficient damage that would generate environmental impacts. These probabilities are listed below.

- The probability of a tornado impacting the sodium bromide tank on the sides not sheltered by the sodium polysulfide tank, process building, or other equipment.
- The probability of a tornado generating a missile.
- The probability of a tornado missile rupturing the outer wall of a tank.
- The probability of a missile rupturing the inner wall of a tank.
- The probability of a missile hitting the tank low enough to have electrolyte escape both the inner and outer tanks.

Because actual probability of these events or catastrophic failure is difficult to quantify, TVA has decided the tanks will be designed to withstand impacts of wind loading and protected from tornado missiles. Tanks will be designed so that any dent or impingement caused by a missile on the outer tank will not impair the integrity of the inner tank. Tank design will be within guidelines of all applicable US codes and under the guidance of the Department of Energy documents referenced by DOE-STD-1020-94; "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities." Consequently, a release will not be caused by tornado winds or tornado generated missiles.

Evaluation of Seismic Hazards

Oliver Springs, Tennessee

The proposed Oliver Springs locations for the Regenesys™ plant fall near the boundary between the Valley & Ridge and Cumberland Plateau physiographic provinces. The Ahler site is located near a thrust fault that separates Cambrian age Rome Formation rocks on the southeast from the Ordovician Age Sequatchie Formation on the northwest (Hardeman 1966). The Rome Formation contains shales, siltstones, limestone and dolomite. The Sequatchie Formation is a shaly limestone with interbeds of calcareous shale and siltstone. The Oliver Springs Substation site is underlain by rocks of the Conasauga Group of Cambrian age. The Conasauga Group rocks in this area are mostly shale with minor amounts of dolomite and limestone. The Coal Creek site lies on top of Pennsylvanian age rocks of the Crooked Fork Group. This sequence of rocks contains shale, sandstone, siltstone, and thin coal beds. The Rome Formation rocks comprise the bedrock geology at the Braden Airport site. All four sites are close enough to streams to potentially have at least a thin layer of soft, Quaternary alluvial deposits on top of the much harder, Paleozoic rocks. The Braden airport site may have a significant thickness of Quaternary alluvial deposits.

The primary source of earthquake hazard to the potential Oliver Springs Regenesys™ sites is from earthquakes originating near (within 100 km) the site (USGS 1996) especially earthquakes from the East Tennessee Seismic Zone. The East Tennessee Seismic Zone is a persistent band of small to occasionally moderate size earthquakes that stretches from northeastern Alabama to extreme southeastern Kentucky (Powell et al 1994).

Based on the 1997 Uniform Building Code (UBC) (ICBO, 1997), earthquake hazard at these potential Regenesys™ sites is moderate (Zone 2A) relative to other locations in the United States. The US Geological Survey (1996) conducted probabilistic seismic hazard mapping for the United States. Table

D-1 presents the USGS's seismic hazard values for a location (36.0° N, 84.3° W) that is very near the proposed Regenesys™ sites. The USGS expresses seismic hazard as the minimum horizontal ground motion that would be expected to occur during a specified time span (return period). The results presented below are for a return period of 2375 years. The ground shaking is computed at four different frequencies of motion: PGA, 5.0, 3.3 and 1.0 Hertz. In the same way that the "100 or 500 year flood" means the level of flooding expected to occur at least once during those periods of time, a ground shaking return period refers to the minimum level of ground shaking expected during the specified time. In this case, Table D-1 shows that at a frequency of 1.0 Hertz, the ground should shake with a force of 14.1% g or greater at least once in 2375 years (g is the acceleration of a falling object due to gravity). The 2375 year return period is equivalent to a 1 in 50 chance that the ground shaking will be exceeded in only 50 years.

Table D-1. Probabilistic ground motion values

	Ground Acceleration in % g
Ground Motion Frequency (Hertz)	2% Probability of Exceedance in 50 yr (2375 year return period)
Peak Ground Acceleration	27.1
5.0	50.7
3.3	38.1
1.0	14.1

Source: USGS 1996

Tanks will be designed to withstand the impacts of the seismic events consistent with the level of seismic hazard computed by the USGS (1996). The seismic design will comply with the requirements of the most recent edition of the UBC as appropriate and, as needed, the guidance contained in the Department of Energy documents referenced by DOE-STD-1020-94; "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities" will be used in design and construction. Consequently, a release will not occur for the design basis earthquake.

These potential Regenesys™ sites are located in a region of moderate to high incidence of landslides (at least 1.5% of the area is involved in landslides and in some areas more than 15% of the area is involved) and high landslide susceptibility (Radbruch-Hall et al. 1982). Landslides could be triggered by earthquakes, heavy rains or a combination of both. The design and exact location of this facility will consider the possibility of landslides.

The potential Oliver Springs Regenesys™ sites, with the exception of the Coal Creek property, appear to lie within or near the floodplain of small streams, therefore, the foundation materials may be susceptible to earthquake induced liquefaction. The liquefaction susceptibility of the foundation materials will be determined through geotechnical testing of materials penetrated in boreholes drilled at the project site. Testing of these materials will also determine to what extent the foundation materials would be expected to increase the intensity of earthquake shaking, if any.

Mountain City, Tennessee

The proposed Mountain City locations for the Regenesys™ plant fall within the Blue Ridge physiographic province. The Shouns Substation and Mountain City Industrial park sites are underlain by Quaternary-age alluvial deposits which cover Cambrian-age sedimentary rocks of the Rome Formation. The Johnson County Industrial Park site is also underlain by the Rome Formation but there are no Quaternary-age alluvial deposits at this site. The Rome Formation contains shales, siltstones, limestone and dolomite (King and Ferguson 1960, and Hardeman 1966).

The primary source of earthquake hazard to the Regenesys™ site is earthquakes originating near (within 100 km) the site (USGS 1996). The Charleston, South Carolina seismic zone is a significant contributor to the earthquake hazard for longer period (1 second or greater) ground motion.

Based on the 1997 Uniform Building Code (ICBO, 1997), earthquake hazard at the Regenesys™ site is moderate (Zone 2A) relative to other locations in the United States. The US Geological Survey (1996) conducted probabilistic seismic hazard mapping for the United States. Table D-2 presents the USGS's seismic hazard values for a location (36.4° N, 81.8° W) that is very near the proposed Regenesys™ sites. The USGS expresses seismic hazard as the minimum horizontal ground motion that would be expected to occur during a specified time span (return period). The results presented below are for a return period of 2375 years. The ground shaking is computed at four different frequencies of motion: PGA, 5.0, 3.3 and 1.0 Hertz. In the same way that the "100 or 500 year flood" means the level of flooding expected to occur at least once during those periods of time, a ground shaking return period refers to the minimum level of ground shaking expected during the specified time. In this case, Table D-2 shows that at a frequency of 1.0 Hertz, the ground should shake with a force of 13.1% g or greater at least once in 2375 years (g is the acceleration of a falling object due to gravity). The 2375 year return period is equivalent to a 1 in 50 chance that the ground shaking will be exceeded in only 50 years.

Table D-2. Probabilistic Ground Motion Values

	Ground Acceleration in % g
Ground Motion Frequency (Hertz)	2% Probability of Exceedance in 50 yr (2375 year return period)
Peak Ground Acceleration	22.6
5.0	42.2
3.3	33.2
1.0	13.1

Source: USGS 1996

Tanks will be designed to withstand the impacts of the seismic events consistent with the level of seismic hazard computed by the USGS (1996). The seismic design will comply with the requirements of the most recent edition of the UBC as appropriate and, as needed, the guidance contained in the Department of Energy documents referenced by DOE-STD-1020-94; "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities" will be used in design and construction. Consequently, a release will not occur for the design basis earthquake.

These potential Regenesys™ sites are located in a region of high incidence of landslides (greater than 15% of the area is involved in landslides) and high landslide susceptibility (Radbruch-Hall et al 1982). Landslides could be triggered by earthquakes, heavy rains or a combination of both. The design and exact location of this facility will consider the possibility of landslides.

With the exception of the Johnson County Industrial Park site, the Mountain City Regenesys™ sites appear to lie within the floodplain of a small stream; therefore, the foundation materials may be susceptible to earthquake induced liquefaction. The liquefaction susceptibility of the foundation materials will be determined through geotechnical testing of materials penetrated in boreholes drilled at the project site. Testing of these materials will also determine to what extent the foundation materials would be expected to increase the intensity of earthquake shaking, if any.

Scenario B, Tanker Offloading

Sodium bromide and sodium polysulfide are delivered to the site by tankers. Each chemical is delivered to site in an uncharged state, which means no bromine is present during offloading operations. Tanker offloading areas are located in separate curbed areas, and any spills are directed to individual tanker sumps. Any spilled electrolyte would be recovered using a portable vacuum tank and removed for disposal at a licensed treatment facility.

Scenario C, Leak Inside the Process Building

A number of events may give rise to minor electrolyte releases in the process building, such as minor leakage from pipework, flanges, etc. These spills are detected and contained within the process building, as described below.

The electrolyte supply pipework from each tank into the building is double walled, and any leaks are directed into the tank annulus. Since the electrolyte is circulated in an enclosed system, bromine can only be released in the event of pipework failure, or a leak from a module in the process building.

Gas sensors located in the process building are designed to initiate an emergency shutdown of the system in the event that greater than trace amounts of bromine are detected. Spilled electrolyte would naturally drain into the ground-floor process-area sump which has gas and level detection monitoring as well. This again would initiate an emergency shutdown. Contents of the sump would be neutralized and removed for disposal at a licensed treatment facility. If gas above trace levels is detected, the emergency ventilation fan will operate and direct the air stream in the process building to the emergency wet scrubber. Under emergency conditions, the bromine emissions are estimated to be approximately 0.1 lb per hour. Emergency operations will be infrequent.

Should a larger electrolyte release occur inside the process building, it would be contained within the ground floor process area, which provides approximately 350 m^3 volume containment. Spillage would be treated as described above.

During emergency operation, the system is expected to increase bromine concentration no more than 8.2 $\mu g/m^3$. The 8-hour threshold level for bromine is 700 $\mu g/m^3$.

Since it is a strong base, sodium polysulfide must be kept away from acids, as it will react and produce hydrogen sulfide gas. Since acids will not be stored or handled in the energy storage facility, release of hydrogen sulfide will be highly unlikely. If hydrogen sulfide is produced, the carbon-bed ventilation system will remove all but trace quantities of the gas. The ventilation and emission control equipment is described in detail in Appendix A.

The tanks have a double containment design; therefore any electrolyte leaks from the inner tank are contained by the outer tank. The tank annulus also prevents release of any bromine gas into the environment. Consequently, any leakage from the inner tank wall will be contained with no environmental impact.

The tanks and secondary containment space between the inner and outer walls are fitted with vacuum and pressure-relief valves. These valves are vented through the ventilation system via carbon-bed adsorbers. Gas monitoring within the annulus provides early detection of any leakage. Level detection within the annulus provides an additional detection system.

Electrolyte storage tank outlets are fitted with two actuated isolation valves, one within the annulus and one outside the annulus. Valves close on unexpected drops in tank level, sudden loss of flow, level rise in the tank annulus, gas detection in the process building, or level rise in the ground floor process area sump. The valve within the annulus is also fitted with an extended spindle to permit manual override, allowing for operation from outside the tank. One valve is electrically operated, while the other is pneumatic. This design prevents common mode failure.

Due to safeguards inherent in the construction of storage tanks, electrolyte leakage is highly unlikely. A containment wall will provide additional containment to prevent electrolytes from entering water sources. Thus, potential direct, indirect, and cumulative effects to surface water resulting from operation of the proposed facility would be insignificant. A spill response management plan would also be developed by TVA.

Fire Induced Toxic Gas Releases

In the unlikely event of a fire inside or around the plant, the chemical electrolytes were reviewed to determine fire hazards. The electrolytes are non-flammable.

Sodium bromide solution is not flammable and correspondingly has no flash point, flammability limit, or auto ignition temperature. The CERCLA and National Fire Protection Association (NFPA) ratings for fire and reactivity are zero on a scale of 0 to 4. Solutions of sodium polysulfide have a rating of zero for flammability and zero for reactivity according to NFPA ratings. In addition, no other flammable materials that could give rise to a fire will be used in the process or stored within the main building.

Any potential environmental impact from fire within the facility is minimal.

Summary

In order to assess whether any additional risks have been introduced as a result of building the plant at one of the proposed sites, an internal review of the design was carried out by TVA specialists identifying scenarios outlined above. Additional design reviews have also been scheduled to ensure the final plant design fully takes into account such risks. The plant will be designed so that it complies with all US codes and standards. These reviews will involve specialists drawn from TVA, Innogy, the architectural engineer, and the construction contractor.