

**NATURAL PHENOMENA HAZARDS EVALUATION OF EQUIPMENT AND PIPING  
OF  
GASEOUS DIFFUSION PLANT URANIUM ENRICHMENT FACILITY**

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**ABSTRACT**

In support of the Gaseous Diffusion Plant Safety Analysis Report Upgrade program (GDP SARUP), a natural phenomena hazards evaluation was performed for the main process equipment and piping in the uranium enrichment buildings at Paducah and Portsmouth gaseous diffusion plants. In order to reduce the cost of rigorous analyses, the evaluation methodology utilized a graded approach based on an experience data base collected by SQUG/EPRI that contains information on the performance of industrial equipment and piping during past earthquakes. This method consisted of a screening walkthrough of the facility in combination with the use of engineering judgement and simple calculations. By using these screenings combined with evaluations that contain decreasing conservatism, reductions in the time and cost of the analyses were significant. A team of experienced seismic engineers who were trained in the use of the DOE SQUG/EPRI Walkdown Screening Material was essential to the success of this natural phenomena hazards evaluation.

**INTRODUCTION**

The Paducah Gaseous Diffusion Plant (PGDP) and the Portsmouth Gaseous Diffusion Plant (PORTS) are the United States Enrichment Corporation (USEC)

facilities which are, by contractual agreement, managed and operated by Lockheed Martin Utility Services (LMUS), Inc.

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The PGDP is located in McCracken County, Kentucky. The cascade operation for enrichment of uranium is performed mainly in four large process buildings (also known as cascade buildings) C-331, C-333, C-335, and C-337. The PORTS is located in Pike County, Ohio. The cascade operation for enrichment of uranium is performed mainly in two large process buildings X-330 and X-333.

Each building contains several diffusion units and each diffusion unit consists of multiple cells. There are eight to ten stages in each cell. Each stage comprises of a compressor, a process motor to drive the compressor, a converter and the connecting piping systems. The equipment and piping systems are routed in the same manner in these numerous cells, cell bypass, unit bypass and tie lines connecting process buildings. The equipment and the main process piping are enclosed in heated housings. The housing floor (for cell bypass, unit bypass and tie lines piping systems), walls and roof panels are made of galvanized steel and/or asbestos cement sheets. The contents of the primary piping systems and equipment is gaseous uranium hexafluoride ( $UF_6$ ).

The objective of this evaluation was to support the plant safety analysis report upgrade program. The equipment and the piping system whose failure could result in potential offsite release of hazardous material were identified. The capacity and demand were calculated for the evaluation basis criteria. The annual probability of failure of components were calculated.

## GOVERNING EVALUATION CRITERIA

The governing criteria for the evaluation, modification, or upgrade of existing DOE facilities for protection against natural phenomena hazards are given in DOE Order 6430.1A [1]. The detailed criteria and guidelines to assure uniform design/evaluation are provided in DOE-STD-1020[2]. The design/evaluation of DOE facilities shall meet the acceptance criteria (performance goals, as specified in DOE-STD-1020) for the usage category of the facility which is evaluated.

## SEISMIC HAZARD

The evaluation basis earthquake (EBE) for Paducah was 0.20g peak ground acceleration (PGA) and for Portsmouth 0.10g PGA both with a return period of 500 years. The earthquake hazard curves for Paducah and Portsmouth are shown in Figure 1. The damping value used in equipment and piping systems evaluation was 5%

of critical. Coulomb damping was used in special cases where sliding could occur.

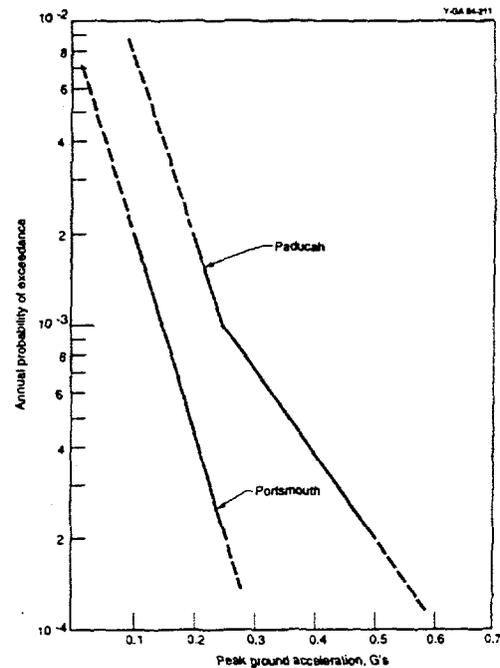


Figure 1 Earthquake Hazard Curves

## WIND/TORNADO HAZARD

### Straight Winds due to Wind/Tornado Hazard

A basic wind speed (fastest mile speed from Table 3-2 of DOE-STD-1020) of 144 mph for Paducah and 110 mph for Portsmouth was used. The fastest-mile wind speeds of 144 mph at Paducah and 110 mph at Portsmouth are most likely produced by tornados. Tornado winds are evaluated just like straight winds but atmospheric pressure change and tornado-borne missiles must be considered. An importance factor, I, of 1.0 exposure category C was applicable to both sites.

Structures which are not sealed or with an opening of 1 ft<sup>2</sup> per 1000 ft<sup>3</sup>, which can be caused by missile perforation, should be subjected to the internal pressure. For sealed structures, with openings less than 1 ft<sup>2</sup> per 1000 ft<sup>3</sup>, atmospheric pressure change (APC) with the tornado vortex should be considered instead of internal pressure. The atmospheric pressure change is always an outward pressure and is applied without additional wind loads. However, sealed structures must be checked for resistance to the combination of maximum wind load and one-half of maximum APC pressure.

### Tornado Generated Missiles Hazard

Two high velocity missiles (due to tornado winds) are postulated for a PC-3 facility as given in Table 3-1 of DOE-STD-1020.

The missiles are

- a 2" x 4" timber plank weighing 15 lb capable of 100 mph horizontal velocity or a vertical velocity of 70 mph with a maximum height of 150 feet;

- a 3-inch diameter standard steel pipe weighing 75 lb capable of 50 mph maximum horizontal velocity or a vertical velocity of 35 mph with a maximum height of 75 feet.

### FLOOD HAZARD

The evaluation criteria for this hazard are given in DOE-STD-1020. However, this hazard does not affect any of the process buildings as the buildings grade levels were above probable maximum flood level for each site.

### *DEFINITIONS, ACRONYMS, AND NOMENCLATURE*

#### DEFINITIONS

**Dead load** — self-weight of the component, contents and insulation plus the weight of permanently mounted associated components (valves, flanges, expansion joints, etc.).

**Failure** — component's anchorage does not perform its function or the component does not maintain its pressure boundary integrity or function.

**Functional capability** — the capability of the system to maintain system fluid temperature, pressure, and flow rate.

**Hard targets** — components that are not susceptible to damage as a result of seismic interaction. These components include welded steel piping and manual or check valves. (Note: cast iron components are not hard targets).

**Outlier** — an equipment, piping/pipe support configuration that is not in conformance with the general criteria defined in the walkthrough guidelines.

**Position retention** — the ability of a component to maintain its position within a permissible space envelop during and after an earthquake.

**Pressure boundary integrity** — the ability of a component to retain internal pressure without loss of pressure.

**Seismic Review Team** — a group of two or more walk-through team members working together to make judgments regarding seismic ruggedness and to ensure technical accuracy of the information collected.

**Soft targets** — components that are susceptible to damage as a result of seismic interaction. These components include fire protection sprinkler heads, pressure gages and instrumentation, nonductile components, etc.

**Unstable anchored (sensitive) equipment** — equipment whose lateral stability is uncertain under earthquake loadings and whose anchorage failure could lead to the equipment overturning and introducing large displacements to the connected piping.

#### ACRONYMS

ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
DOE	Department of Energy
EBE	Evaluation Basis Earthquake
EJMA	Expansion Joint Manufacturers Association
EPRI	Electric Power Research Institute
GDP	Gaseous Diffusion Plant
GRS	Ground Response Spectrum
HCLPF	High Confidence Low Probability of Failure
IRS	Instructure Response Spectrum
LMES	Lockheed Martin Energy Systems
LMUS	Lockheed Martin Utility Services
NPH	Natural Phenomena Hazards
NRC	Nuclear Regulatory Commission
PGA	Peak Ground Acceleration
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
SARUP	Safety Analysis Report Upgrade Program
SQUG	Seismic Qualification Utilities Group
SRT	Seismic Review Team
SSC	Structures, Systems, or Components
USEC	United States Enrichment Corporation

#### NOMENCLATURE

$A_{HCLPF}$	=	HCLPF acceleration value (g)
$g$	=	acceleration due to gravity (ft/s <sup>2</sup> or inch/s <sup>2</sup> )
$P_H$	=	annual probability of hazard exceedance
$P_f$	=	annual probability of failure

## **LOADING COMBINATION**

The dead loads, normal loads and the hazard loads were combined in the evaluation of each hazard condition.

## **EVALUATION METHODOLOGIES**

### **SEISMIC HAZARD EVALUATION**

The basic approach employed in the evaluation of equipment and piping systems for seismic loads followed the general philosophy of the experience-based methods used by the commercial nuclear power industry to resolve the NRC Unresolved Safety Issue A-46 as proposed by the Seismic Qualification Group (SQUG) and reviewed by the Senior Seismic Review and Advisory Panel. This data base was compiled by SQUG/EPRI and is known as Generic Implementation Procedure (GIP) [3]. This SQUG/EPRI GIP methodology was approved by the NRC and is in use by the nuclear industry for the evaluation of existing nuclear power plants. This methodology with some modifications was also adopted by DOE for the seismic evaluation of DOE facilities[4]. This procedure, hereafter, referred to as DOE/SQUG GIP, was utilized for the seismic evaluation of equipment and piping components.

Although the current SQUG scope includes valves, it does not include piping or pipe supports. Extensive data accumulated during the last decade from laboratory tests and post-earthquake investigations identify the types of pipe system configurations that are potentially vulnerable to seismic effects. The experience database approach was extended to piping and pipe supports.

The seismic evaluation of equipment, piping, associated piping supports, and associated piping components (valves, expansion joints, etc.) was a three-step operation. In the first step the equipment and piping systems whose failure could cause offsite release of hazardous material were identified by consulting with accident analysis personnel and by a review of drawings. In the second phase a walkthrough screening of selected scope of work was performed to identify the items potentially vulnerable to seismic effects (weak links and outliers). The third phase was for structural evaluation of these weak links and outliers by analytical (static or dynamic) and/or other methods. The HCLPF capacities of the vulnerable items were calculated using industry adopted methods [5][6] as a function of the peak ground acceleration. The annual probability of failure was

estimated from the calculated HCLPF capacity and the respective site seismic hazard curve.

In general, seismic analysis of equipment involves identifying the load path to the ground for the inertia forces generated by the earthquake on the equipment. The magnitude of the inertial forces depends on the frequencies and modes of response of the equipment. For the seismic evaluation of equipment an experience data base methodology was developed and documented in K/GDP/SAR-56[7]. This document provides the walkthrough screening guidelines as well as the structural assessment methodology for both the SQUG/EPRI experience data base covered equipment and for the equipment which are not in SQUG data base.

Currently, the piping and the pipe supports are not covered by SQUG/EPRI experience data base. For the seismic evaluation of piping and the pipe supports, an experience data base methodology was developed. Two documents, K/GDP/SAR-57[8] for the walkthrough screening and K/GDP/SAR-58[9] for the structural assessment were developed. These documents utilized the experience data gathered on the performance of piping systems during past earthquakes by the industry[10][11]. The piping and pipe supports were inspected per the guidelines given in K/GDP/SAR-57. The subsequent seismic structural assessment of the piping and pipe supports outliers was performed per the methods provided in K/GDP/SAR-58.

The expansion joints were inspected using the walkthrough guidelines that were developed[12]. The walkthrough screening form was slightly modified to gather the relevant data. The structural assessment (pressure integrity, movements, etc.) of the expansion joint was performed per the methodology given in, "Standards of the Expansion Joint Manufacturers Association"[13]. The fatigue life calculations of the expansion joints were performed per ASME code, Section III[14].

The component seismic verification logic diagram is given in Figure 2. The methods used to evaluate outliers progressively removes conservatism from the seismic capacity calculated but requires increasing time and cost. It is not necessary to proceed to the next level if it could be shown that the capacity was greater than the demand or if more rigorous methods would not be expected to yield significantly higher seismic capacity.

### **Walkthrough Screening**

The purpose of the walkthrough screening is to identify those equipment and piping system features that

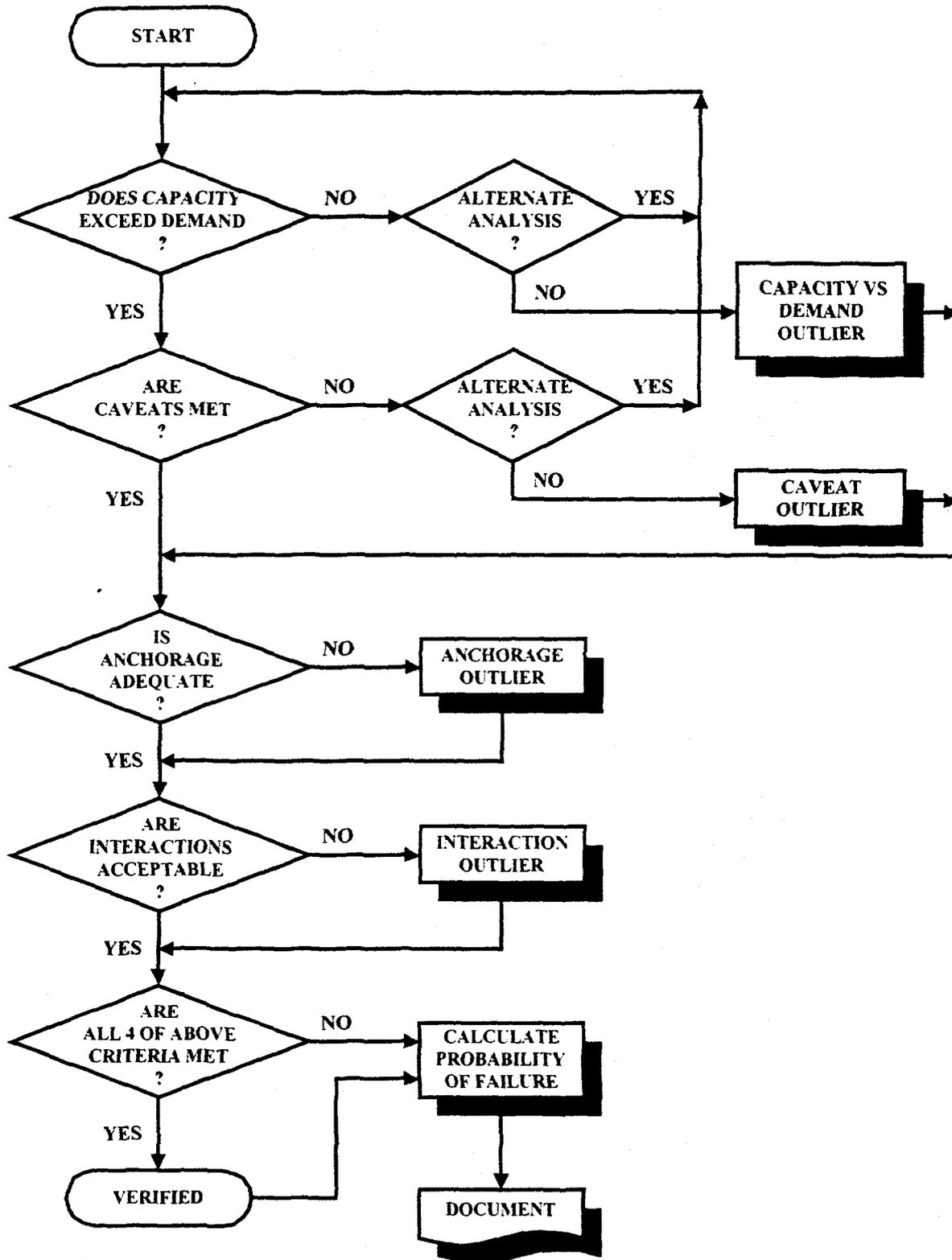


Figure 2 Seismic Verification Procedure

require further evaluation to estimate general seismic capacity. The walkthrough screening criteria consisted of the evaluation of selected equipment, piping systems or segments of piping systems, pipe supports and their anchorage, associated piping components (valves, expansion joints, etc.) and potential proximity or spatial interactions. The focus of the screening criteria is to identify conditions that earthquake experience identified as susceptible to failure. A failure is defined as a loss of pressure boundary integrity (containment) or functionality.

The seismic review walkthrough team consisted of a minimum of two qualified seismic engineers, with at least one registered profession engineer. The walkthrough team received training in DOE/SQUG GIP and met all the requirements given in the various guidelines documents.

Several meetings were held with the plant personnel for specific site training, permits and schedules prior to the walkthrough. Design data pertinent to walkthrough screening was collected and reviewed prior to the start of the walkthrough. The walkthrough team gathered the data as required per the checklist given in the walkthrough screening guidelines. The walkthrough team ensured that all required data are correctly recorded, completed, and signed by all walkthrough team members.

### Equipment

The walkthrough screening of the equipment was performed using the screening forms given in K/GDP SAR-56. The load path to the ground for the inertia forces generated by the earthquake in the equipment was traced. The general condition of the supporting structure (concrete cracks, anchorages, etc.) was particularly noted. The flexibility of the attached lines were also assessed. Any equipment which did not meet the appropriate screening criteria given in K/GDP/SAR-56 was classified as an outlier.

### Piping and Pipe Supports

The walkthrough screening of the Piping and the associated piping supports were performed using the screening forms given in K/GDP/SAR-57. All attributes, e.g., span lengths, ductile material, non standard fittings, weld quality, concrete and anchorage quality, anchorage edge distance, external corrosion, etc. which could lead to a potential seismic vulnerability were identified and recorded. Also, the question of potential internal corrosion due to the piping contents ( $UF_6$ ) was addressed. Attention was concentrated toward identifying the weak links. Any piping segment and/or pipe support which did not meet the

screening criteria given in K/GDP/SAR-57 was classified as an outlier.

### Air and Motor Operated Valves

The walkthrough screening of the associated piping air and motor operated valves were performed per DOE/SQUG GIP. The seismic evaluation work sheets (SEWS) provided in a DOE training course were utilized in the walkthrough screening of these valves. The main items of interest here were the valve operator height, valve motor operator location, and valve operator supporting structure.

### Expansion Joints

The walkthrough screening of the associated piping expansion joints were performed using the guidelines given in reference 10. The basic configuration (general location, obvious misalignment, etc.) was visually confirmed. Special attention was given to assure that all shipping and installation devices have been removed or, if present, they do not interfere with the design intent of the expansion joints. Noticeable defects (dents, gouges, external corrosion, pitting, weld splatter, surface cracks, etc.) and potential interaction that could affect the functionality of the expansion joint were recorded.

### Structural Assessment

The equipment and the piping systems (including the associated pipe components) evaluated were cell stage components, cell bypass piping, unit bypass piping, and tie lines piping (connecting the process buildings). Stage components were located on the cell floor of the process buildings. The components in a typical stage consist of a process motor, compressor, converter, recycle cooler, and connecting pipes with associated piping components.

The structural assessment consisted of evaluating the attributes identified through implementation of the walkthrough screening guidelines to determine the seismic level or capacity, in terms of peak ground acceleration, that the equipment and piping are capable of resisting. The seismic level or capacity was then related to the annual probability of failure.

The methods used to evaluate outliers progressively remove conservatism from the seismic capacity calculated. In all cases the calculation were performed in accordance with the intent of criteria given in DOE-STD-1020.

To resolve outliers the following levels of methodology was used.

1. Engineering judgement can be used for obviously rugged component or subcomponent. This covers a broad range of structural and mechanical equipment. This judgement should be based on a thorough understanding of the screening guidelines and the background philosophy used to develop the guidelines.
2. A weak link analysis is appropriate if it can be readily determined in the walkthrough or by a review of design drawings. It can also be used for component which does not have an obvious weak link if by evaluating a subcomponent, such as the anchorage, a large seismic margin can be calculated.
3. A simplified analysis can be performed based on a simplified load path which allows a conservative evaluation of a joint or anchorage. This would include static analysis of dynamic loads using the static force method.
4. More sophisticated and detailed engineering analyses may be performed to more carefully and/or accurately evaluate the seismic capacity of the equipment and/or the seismic demand to which it is exposed. This could extend to finite element modeling of varying complexity and detail. The object is to remove the conservatism introduced by assumptions made in applying judgement or simplified analysis.
5. Testing may be used to more accurately determine equipment dynamic properties. This could include in-situ tests or shake table tests.

Seismic capacity was calculated by analysis for the components (equipment and piping systems) which did not meet the screening criteria given in the respective walkthrough screening guidelines. The following methodology was used in the component evaluation:

1. Analyze the component using the IRS as the seismic loading and compute the elemental stresses or loads.
2. Calculate the demand stress or load (DEMAND) from the evaluation basis earthquake and by adding nonseismic loads

(expected to be acting concurrently with an earthquake) to the seismic loads.

3. Calculate the stress or load capacity consistent with a High Confidence of Low Probability of Failure (CAPACITY) of the element by multiplying the appropriate code allowable by 1.4 for shear in members and bolts, and 1.7 (or 1.6) for all other steel elements.
4. Calculate the acceleration capacity ( $A_{HCLPF}$ ) of the component by multiplying the ratio of the allowable stress (CAPACITY) to the calculated stress (DEMAND) times the Peak Ground Acceleration (PGA).

$$A_{HCLPF} = PGA \times \frac{CAPACITY}{DEMAND}$$

The DEMAND and PGA are based on EBE.

5. The annual probability of failure due to a seismic event is related to the seismic capacity by the site seismic hazard probability curve. Enter the site seismic hazard curve with an acceleration corresponding to 1.5 times the  $A_{HCLPF}$  as calculated above and determine the annual probability of exceedance,  $P_H$ . The annual probability of failure,  $P_F$ , is approximately equal to  $P_H/2[6]$ .

#### Equipment

The structural evaluation of the equipment were performed per the methodology given in DOE/SQUG GIP and/or that given in K/GDP/SAR-56. Structural calculations for outliers were performed using either hand calculations or simplified computer static analysis models.

The process motors were evaluated using the DOE/SQUG methodology. The compressors, converters, recycle coolers were evaluated as outliers by the K/GDP/SAR-56 methods.

#### Piping and Pipe Supports

The structural evaluation of piping segment/pipe support outliers were performed per the methodology given

in K/GDP/SAR-58. The emphasis was to identify and evaluate the weak links and outliers in the system. Structural calculations were performed using either the hand calculations or the simplified computer static analysis models.

### Air and Motor Operated Valves

Since the valves are not required to function, the structural integrity evaluation of the valves on the piping system was not performed. These valves are rugged. The only possible failure is the bending of valve stems which can result in leakage of UF<sub>6</sub>.

### Expansion Joints

The structural assessment (pressure integrity, movements limits, etc.) of the expansion joints were performed per the methodology given in, "Standards of the Expansion Joint Manufacturers Association (EJMA). The calculated demand from the thermal, seismic, etc. is imposed on the bellows. The EJMA equations were used to calculate the capacity of the bellows. The EJMA equations basically converts all applied motions (axial, lateral, angular) on the bellows into equivalent axial motion. The capacity of the bellows is a function of the bellows number of convolutions, pitch, depth, etc. The fatigue life calculations of the expansion joints were performed per ASME code, Section III.

## **WIND/TORNADO HAZARD EVALUATION**

Wind/Tornado evaluation and tornado generated missiles impact evaluation was performed to the requirements given in DOE-STD-1020.

Also, during high winds, the building siding can fall on the housings which in turn can fail and fall on the equipment and piping systems.

### Straight Winds due to Wind/Tornado Hazard

Although the equipment and the pipe systems being evaluated are all inside the process buildings, the evaluation of the building indicated that the building shell can be stripped away by winds with speed less than the evaluation basis wind speed. Thus, the equipment and the piping systems can be exposed to high speed wind.

Following the methodology given in ASCE 7[15], the basic wind pressure,  $q_z$  at height  $z$  is:

$$q_z = 0.00256K_z (IV)^2$$

Where the wind speed  $V$  is the fastest mile speed at the site and the importance factor,  $I$ , is 1.0. The velocity pressure coefficient,  $K_z$ , is a function of height above ground and the exposure of the equipment. Exposure C, which is open terrain, was used.

Wind force was calculated as:

$$F = q_z [GC_p - GC_{pi}] A_f$$

where,

$GC_p$  is an external pressure coefficient that depends on the tributary area of the equipment

$GC_{pi}$  is an internal pressure coefficient that depends on the relative size and distribution of openings on the sides of the equipment

$A_f$  is the projected area of the equipment normal to the wind.

These coefficients are available in ASCE 7. One-half of the APC pressure exceeds the internal pressure, so for the outward pressure case -20 psf was substituted for  $q_z GC_{pi}$ . The evaluation steps for wind loading due to wind/tornado are as follows.

1. Calculate wind pressure and resultant force on the equipment and piping.
2. Determine stress/load demand based on the basic wind speed. Atmospheric pressure change (APC) forces on process piping and equipment are inconsequential and are ignored. Wind loads are combined as appropriate with dead load and other loads which are normally present.
3. Determine capacity based on the equipment standard design allowable by either allowable stress design (ASD) or strength design (SD) or other criteria such as overturning.
4. If the capacity is less than the demand, calculate the wind speed which correlates with the demand and determine the annual probability of failure from the site wind hazard curve.

### Tornado Generated Missiles Hazard

DOE-STD-1020, requires that two high velocity missiles, as identified in governing criteria, generated due

to a tornado be considered for a PC-3 facility evaluation. The equipment and the main process piping are enclosed in the housings with the housing floor (for cell bypass, unit bypass and tie lines piping systems), walls and roof panels made of galvanized steel and/or asbestos cement sheets and are not effective in resisting missiles.

Using simplified, industry-proven formulae, the barrier thicknesses to stop the two missiles are given in table 3 of reference 16. These tabulated data were utilized in assessing the structural integrity of the various equipment and piping systems.

### **FLOOD HAZARD EVALUATION**

This hazard does not affect any of the process buildings as explained in governing criteria.

### **INTERACTION HAZARD**

A screening evaluation was performed on the equipment and piping and its associated components to identify potential interaction with other systems and structures. These interactions include hazards from the sway of the pipe impacting adjacent structures and components as well as hazards of swinging or falling objects from adjacent structures and components that are not adequately restrained or anchored. These typically are grouped as (1) proximity and (2) spatial concerns. Proximity refers to the potentially adverse effect from the seismic motion of one component or structural element onto another. Spatial concerns refer to the potential for the falling of a component and its subsequent effect on the piping and its supports.

In a seismic event the bridge cranes inside the building can potentially fall and damage equipment and piping systems. Cranes were evaluated in their parked positions. The HCLPF acceleration ( $A_{HCLPF}$ ) value was determined to be greater than the site PGA of the evaluation basis earthquake.

Other credible sources of seismic spatial interactions are the cells, cell bypass, unit bypass and tie line housings failing and impacting the process gas piping being evaluated. Also during high winds, the building siding can fall on the housings which in turn can fail and fall on the equipment and piping systems. The housings are steel frame structures with shop welded/field bolted connections. The steel frame members are thinner than the piping and is low mass structure with high damping. Thus, they are not postulated to cause a failure of

equipment and piping systems. However, the expansion joints are vulnerable to puncture due to impact by the housing structure.

### **CONCLUSIONS**

Because of the large number of the similar configuration of equipment and the piping systems, this method proved to be a very practical and economical way of accomplishing the objectives. The key to achieve high confidence in evaluation was an experienced team of seismic engineers. The SRT was called upon to make good engineering judgements during walkthrough screening and in subsequent structural evaluation of the outliers. A peer review by outside industry experts was also a big contributing factor in assuring the quality of the process.

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