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**Ventilation Systems Analysis
During Tornado Conditions**

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W. S. Gregory
R. W. Andrae
K. H. Duerre
R. C. Dove

**los alamos
scientific laboratory**

of the University of California

LOS ALAMOS, NEW MEXICO 87545

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VENTILATION SYSTEMS ANALYSIS DURING TORNADO CONDITIONS

by

W. S. Gregory, R. W. Andrae, K. H. Duerre, and R. C. Dove

Abstract

A computer code, TVENT, has been developed to predict the tornado-induced pressures and flows within an arbitrary nuclear facility ventilation system. Operational experience with TVENT in analyzing an ERDA facility has resulted in code modifications. Several architectural firms have agreed to use TVENT to analyze their designs. They will provide us with comments on the code and user's manual to make them more useful. Our investigation of the feasibility of scale model analysis to provide additional comparative data and preliminary results is presented. Preliminary calculations indicate that a distorted model would be necessary. Distortion of the Reynolds number relating the model to the prototype appears to be the most practical approach.

The Idaho Chemical Processing Plant (ICPP) atmospheric protection system was analyzed using TVENT, and the results are presented. They were found to be in close agreement with the real system under steady-state conditions. For a tornado at the exhaust stack, TVENT predicted a flow increase of 70% through the system's HEPA filters.

I. INTRODUCTION

The principal objective of this program is to provide the analyst with a tool for determining tornado-induced air flow and pressure magnitudes within a nuclear facility ventilation system. The analytical tool developed is the digital computer code TVENT. TVENT and a preliminary user's manual were completed in October 1976. The principal features of the code are:

- o Steady-state and transient pressure and flow distributions are calculated.
- o The code input is organized in a way that should be "natural" to the analyst preparing the data.
- o The code is written in FORTRAN IV language and is designed to be "portable"; that is, it is easily transferred from one computer to another with a minimum of change.

- o The input is sufficiently flexible to permit runs that will verify an existing design or permit parameter studies for insight into the effects of design value changes.
- o The program is easily modified.

With these features, TVENT provides the analyst with an economical and reasonably accurate approach to determining tornado loadings on planned or existing nuclear facilities.

Since the code was to be user oriented and had not been applied to an actual ventilation system, a trial period was set aside in FY 1977 to

- o allow a "friendly user" to apply the code to existing or planned ventilation systems,
- o analyze several actual Energy Research and Development Administration (ERDA) facilities, and

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- o explore the feasibility of obtaining additional code verification through scale modeling.

Several architectural engineering firms were contacted about their willingness to serve as "friendly users" of TVENT. Comments are being solicited from the system designers in the responding firms regarding the ease of applying TVENT. Feedback on user document ambiguities, lack of needed features, relevance of existing features, errors detected in the user's manual and computer code, and the effect of code size will contribute toward making TVENT a successful analytical tool. Test data resulting from comparison with output of other computer codes together with assumptions made and system descriptions will also be useful in determining the validity of TVENT results.

Among the ERDA facilities identified to be analyzed by TVENT during FY 1977 are the Idaho Chemical Processing Plant (ICPP), the Savannah River Fuel Form Fabrication Plant (PuFF), and the Los Alamos Scientific Laboratory (LASL) plutonium facility. This report contains only the results of our application of TVENT to the ICPP facility.

Verification of TVENT results by comparison with the depressurization of an actual ventilation system is impossible in any practical sense because of the tremendous quantities of air involved. Comparative results can be obtained by physical scale modeling of a ventilation system, and then depressurizing this smaller system. However, in many instances tests of scale model systems can also be impractical to perform.

Consequently, we have initiated a study to determine the feasibility of physical modeling. In this study we will establish scaling laws, determine the suitability of different scales, specify auxiliary tests to be performed, prepare test specifications, and design a scale model. This report contains the initial calculations used to establish the scaling laws and the requirements for proper geometric, time, velocity, and pressure scaling.

II. ERDA FACILITY ANALYSIS-ICPP VENTILATION SYSTEM

A. General Description

The ICPP is an ERDA facility operated by Allied Chemical Corporation for recovering fissile materials from reactor spent-fuel elements. The plant complex

consists of four relatively isolated facilities: analytical laboratory, fuel processing, waste treatment, and waste calcining. The ventilation air from all these facilities except the analytical laboratory is carried through a system of external ductwork to a centrally located Atmospheric Protection System (APS). The air is filtered in the APS before being discharged into the environment by a 250 ft (76.2 m) stack. Most of the analytical laboratory input air is discharged without filtration to the environment by exhaust fans in the roof of the analytical laboratory building. Two supply blowers housed in a service building provide ventilation air to the analytical laboratory and fuel processing facilities. A single supply blower serves the waste treatment facility. Ventilation air is moved from the calcining facility to the APS by supply and exhaust blowers.

Process off-gases (the gases produced during the processing operations) are treated and filtered both at the facility of origin and in the APS. Four main process off-gas systems are in use at ICPP: (a) E-cell dissolver off-gas (E-DOG), (b) aluminum dissolver off-gas (AL-DOG), (c) vessel off-gas (VOG), and (d) waste calcine (WCF) off-gas.

Ventilation air in the APS is rough-filtered through a deep-bed, fiber glass prefilter and then through 104 high efficiency particulate air (HEPA) filters housed in caissons connected in parallel. Process off-gases are given a different treatment depending on their content. Those containing NO_x are processed in acid resistant systems because of the high probability of forming acids. Those rich in hydrogen are handled separately because of potential explosive mixtures.

B. TVENT Analyses

A TVENT model consists of specific system components arranged in their proper flow order and separated by nodal points. The component or group of components connecting two consecutive nodal points is referred to as a branch. Each branch can be described by a mathematical relationship between flow and pressure change. This characteristic relationship is unique for each blower, damper, filter, or duct, and the appropriate function is assigned to each branch. The supply and exhaust locations in a system are the peripheral single-branch nodal points at which boundary pressures are imposed. A flow diagram is usually the best means of defining the

Fig. 1. ICPP Computer Model.

model. Manufacturer's data, actual flow and pressure measurements, and various data found in literature constitute the best sources for evaluating the component characteristics. The solution is obtained by solving the set of branch flows and nodal point pressures that satisfy the conditions established by the system resistances, the blower performance curves, and the boundary pressures. The branch flows are in equilibrium at each nodal point for a steady-state solution. Rooms to represent fluid storage are added at nodal points for the transient solution.

C. Modeling

Modeling of the ICPP system was based on information obtained from P. I. Nelson, ICPP. This information consisted of flow diagram of the ventilation air through the analytical laboratory and fuel processing and waste treatment facilities as it existed before the APS was installed. Blower performance curves for blowers in the APS only were also supplied. Nameplate information was made available for the remaining blowers in the system. In addition, system pressure drops and some key pressures

in the APS were provided. (See Appendix A.) The limited information on the older portions of the facility forces a relatively crude modeling of these areas. However, the APS was more accurately modeled and represents the primary area of interest for this analysis. The model used is shown in Fig. 1.

The branch component characteristics are incorporated as resistance for ducts, dampers, and filters, and as flow vs pressure-rise curves for blowers. Because system resistances are a function of the flow and pressure drop in the real system, their values can be obtained from field measurements.

D. Tornado Transient

The tornado transient is based on information from Ref. 1. The state of Idaho is subject to a Region III intensity tornado defined to have a maximum pressure drop of 1.5 psi (10.3 kPa), or 41.5 in. of water, occurring at the rate of 0.6 psi/sec. (4.1 kPa/s) and a maximum translational speed of 50 mph (22.3 m/s). If the tornado diameter is assumed to be 300 ft (91.4 m), the pressure drop of 1.5 psi would last for about 4 s. The transient just described is shown in Fig. 2.

Fig. 2. Region III Tornado Transient.

E. TVENT Solutions

A steady-state solution at the normal plant operating condition was the first TVENT calculation made. The results of this calculation were used as the starting point for the transient solution and were also used to check the accuracy of the model in simulating the real system. A certain amount of resistance adjustment was necessary to match the measured flows and pressures. The value of these steady-state resistances does not change during the transient solution.

A tornado depressurization would occur at five possible inlet and outlet locations:

- o the main exhaust, node No. 46,
- o the main supply, node No. 47,
- o the roof of the analytical labs, node No. 51,
- o the supply to the waste treatment facility, node No. 6, and
- o the supply to the waste calcining facility, node No. 10.

A list of input data for a TVENT solution with the tornado transient at the main exhaust, node 46, is shown in Appendix B.*

1. Steady-State Solution. Nodal pressures and branch flows for the normal operating condition are tabulated in Appendix C. These data are reduced to differential pressures and flows in the individual model components in Appendix B.

2. Transient Solutions. The maximum effects of tornadoes on the flow through the APS filters are presented in Table I. This information was obtained from the flow-vs-time plots of the individual filter components in the model. These plots are shown in

TABLE I
FLOW EFFECTS THROUGH APS FILTERS

Tornado Condition	Flow in Filters			
	Prefilter Flow (cfm)	Prefilter Flow (m^3/s)	HEPA Filter Flow (cfm)	HEPA Filter Flow (m^3/s)
1. Transient at 250-foot Exhaust Stack Node (46)	179 000	84.5	1723	0.81
2. Transient at main air supply, Node (47)	84 090	39.7	809	0.38
3. Transient at roof of Analytical Laboratory, Node (51)	104 310	49.2	1092	0.47
4. Transient at Waste Treatment Facility, Node (6)	104 680	49.4	1005	0.47
5. Transient at Waste Calcining Facility, Node (10)	88 963	41.8	855	0.40

Normal operating flow is 104,800 CFM ($49.5 m^3/s$) for prefilter and 1050 CFM ($0.48 m^3/s$) for each HEPA filter.

Appendix E. Appendix F is the flow-vs-time plot for the process off-gas systems showing the maximum flows for the 250-ft (76.2-m) exhaust stack tornado condition.

F. Discussion of Results

Table II and Table III show a comparison between normal operating flows and pressures calculated for the model and those obtained for the real system. Model branch and node numbers corresponding to the respective flows and pressures are indicated in Fig. 1. The source of the data obtained for the real system is also given. The modeling appears to be satisfactory because the values are in agreement for steady-state operation. The question of how well the real system is defined in the data in Table II and Table III should be answered before a final judgement is made.

The most critical tornado location for the APS is at the exhaust stack outlet. This is the only boundary where the tornado increases the flow through the filters. A tornado at any of the other boundary locations tends to reduce the flow. Possible modes of failure caused by filter overflow could be structural damage or loss of filtering efficiency. Failure from a reduction in flow could only occur if the flow in the filter reverses and dislodges trapped radioactive particles, allowing them to be carried upstream to some unshielded location. A peak flow of 179 200 CFM ($84.5 m^3/s$) through the prefilter results from a tornado at the exhaust stack. This represents an increase of about 20% over the design flow of 154 000 CFM ($72.7 m^3/s$). Although nothing is known about the structural integrity of the prefilter, it is reasonable to assume that it could withstand this amount of overflow. However, there would be some loss in filtering efficiency. Figure E-2 shows a maximum flow of 6892 CFM ($3.252 m^3/s$) through

* An explanation of this format can be found in an unpublished Los Alamos Scientific Laboratory report "TVENT - A Computer Program for Analysis of Tornado Induced Transients in Ventilation Systems." The authors, R. W. Andrae, K. H. Duerre, or W. S. Gregory can be contacted for information in this report.

TABLE II
ICPP OPERATING CONDITIONS AND TVENT RESULTS

Normal Operating Condition Parameter	Pressure, in. of water (pascals)	
	Model	Real
Pressure at outlet of main supply blowers	P(49) = 1.5 (370)	1.5 (3) (370)
Pressure in Fuel Processing facility cells	P(5) = -0.71 (-180)	-0.65 (3) (-169)
Pressure in Waste Calcining facility corridors	P(12) = 0.24 (59)	0.25 (2) (62)
Pressure in Waste Calcining facility cells	P(52) = -0.76 (-190)	-0.75 (2) (-190)
Pressure in duct at entrance to APS	P(9) = -1.6 (-400)	-1.6 (1) (-400)
Pressure drop across prefilter	P(13) - P(14) = 1.9 (470)	1.8 (1) (450)
Pressure drop across HEPA filter	P(15) - P(41) = 0.70 (170)	0.70 (1) (170)
Pressure upstream of APS Blowers	P(42) = -5.8 (-1400)	-5.0 (1) (-1200)

- (1) P. I. Nelson, ICPP (Appendix)
 (2) FSAR for Atmospheric Protection System, ICP-1082, June 1976, (Ref. 3)
 (3) Supply and Exhaust Air Flow Sheet, Dwg. No. 054336, Feb. 1967 (Appendix)

TABLE III
ICPP OPERATING CONDITIONS AND TVENT RESULTS

Normal Operating Condition Parameter	Flow, cfm (m ³ /s)	
	Model	Real
Flow from main supply blowers	Q(74) = 127 940 (60.37)	128 560 (3) (60.67)
Flow to Analytical Labs	Q(75) + Q(77) = 74 322 (35.07)	74 260 (3) (35.04)
Flow to Fuel Processing facility	Q(4) = 62 720 (29.60)	63 310 (3) (29.88)
Flow from Waste Calcining facility	Q(11) = 11 017 (5.198)	11 000 (2) (5.191)
Flow from Waste Treatment facility	Q(8) = 21 227 (10.02)	21 000 (2) (9.910)
Flow through APS	Q(66) = 104 860 (49.48)	105 000 (1) (49.54)
Flow in H ₂ -rich process off-gas system	Q(87) = 50 (0.023)	50 (2) (0.023)
Flow in NO _x -containing process off-gas system	Q(92) = 4 261 (2.011)	4 000 (2) (1.887)

- (1) P. I. Nelson, ICPP (Appendix)
 (2) FSAR for Atmospheric Protection System, ICP-1082, June 1976, (Ref. 3)
 (3) Supply and Exhaust Air Flow Sheet, Dwg. No. 054336, Feb. 1967 (Appendix)

a. HEPA caisson that contains four individual filters. An individual HEPA filter is subjected to a maximum flow of 1723 cfm ($0.81 \text{ m}^3/\text{s}$) for this same tornado. The separatorless 24-in. (0.61-m) by 11.5-in. (0.29-m) HEPA's are rated at 1500 cfm ($0.71 \text{ m}^3/\text{s}$) to meet an acceptance criterion of 99.9% filtration efficiency for $0.3\text{-}\mu$ sized particles. The tornado-induced increase is 15% above the rated flow. The only effect of tornado transients imposed upstream of the APS filters is a reduction of flow through these filters. Because the flow does not reverse, there are no damaging effects on the APS filters. The greatest reductions of 20% occur for a tornado at the inlet to the main supply blowers, node No. 47. A tornado at the supply to the waste treatment facility produces a reduction of 15%. The effects of tornadoes at either the supply to the waste calcining facility or the roof of the analytical laboratory building are negligible. The effects of a tornado upstream of the APS appear to be a function of the flow coming from that area and of room volumes through which the transient passes on its way to the APS. A combination of low flow and large room volumes tends to isolate tornado effects on the APS.

Appendix F shows the flow-time curves for the process off-gas systems resulting from the tornado transient at the exhaust stack. The increase in flow for both the hydrogen-rich and the NO_x -containing systems appears to be consistent with the increase indicated in the ventilation air. But because of an almost total lack of operational flow and pressure measurements in these off-gas systems, especially those outside the APS region, we have no confidence that the model accurately simulates the real systems.

G. Conclusions and Recommendations

The 250-ft (76.2-m) exhaust stack is the most critical location that a tornado could hit the APS. The effect is an increase in flow to about 70% over the normal operating flow, 20% over the prefilter design flow, and 15% over the rated flow for the HEPA filters. There would be some loss in filtering efficiency at this high flow, but probably no structural damage.

The increase in flow in the APS from the process off-gas systems appears to be consistent with the flow increase for the ventilation air. Because we lack knowledge about the construction and operation of these systems, we cannot evaluate the probable effects of these increases.

A very good mathematical model can be developed if the following information is available:

- o Architect and Engineering Drawings,
- o Architect and Engineering Calculations,
- o Blower Manufacturers,
- o Flow and Pressure Measurements, and
- o Safety Analysis Reports.

However, a model like the one described herein can be developed without all these data. Although an understanding of the functions of all portions of a system is essential for proper modeling, the level of detailed data needed for modeling varies depending on the proposed use of the analytical results. That is, if the results are to be applied to specific pieces of hardware, the details of these items must be represented in the model.

III. COMPUTER CODE DEVELOPMENT

A. Status of the Computer Code TVENT

A preliminary version of TVENT and the user guide have been completed. The overlay structure and modules are shown in Appendix G. The program has been successfully run on the following computers:

- o CDC 7600,
- o IBM 360,
- o UNIVAC 1108, and
- o UNIVAC 1110.

The differences in results caused by shorter word lengths for the non-CDC computers are insignificant. We feel that our system solver algorithm is the reason for retained accuracy. Our goal of portability has been achieved. The program can handle a system with 500 components and 400 nodal points. Core storage requirements for TVENT are approximately 20 000 decimal words for the overlayed version and 28 000 decimal words for a nonoverlayed version. This should fit on the computers available to most users.

TVENT is being used to analyze existing facilities, and a version of the program is being run by a "friendly" user. Enhancements of the code have resulted from our experience with actual ventilation systems. Output lists have been modified, the plotting feature now accepts fixed upper limits to facilitate comparisons in parameter studies, and additional control information and intermediate results have been included to aid in debugging the input data.

B. Operating Experience

The TVENT program has been successfully applied to analysis of the air protection system of the ICPP facility. Our model (Fig. 1) included 9 blowers, 12 rooms, 31 filters, 45 dampers, and 7 ducts requiring 93 branches and 65 nodal points. This facility is typical of many in that it is several years old and much of the design information is unavailable or outdated for modeling purposes. Design flows were obtained from early drawings, but only five pressures are known for the system. Only two of the blower characteristic curves were available during the early modeling stages. With so little information available, the problem of determining system resistance was acute.

We developed an approach that can be applied to other systems lacking in detail. First, we provided blower curves that were nearly vertical, intercepting the flow axis at the design flow value. Second, the known pressures were made internal fixed boundary nodes. Thus estimates of pressure drops and system resistance could be determined. Then internal boundary nodes were removed and the correct blower curves were used as they became available. The design flows and known pressures were verified prior to imposing the Region III tornado transient.

Convergence problems were encountered during the transient calculations. These problems were traced to blower operation near zero slope on the input blower characteristic curve. The blower curves are approximated by a series of straight line segments as illustrated in Fig. 3. The source of the problem was difficult to identify, and consequently more detailed transient monitoring and appropriate messages have been installed in the code to indicate this condition.

Our system model contains more detail than required for the basic analysis. The parallel arrangement of 26 HEPA filter caissons could have been replaced by one filter with an appropriate flow area. Similarly, the two process off-gas lines labeled E-DOG and VOG with design flows of 50 and 4000 cfm, respectively, were removed from the model with a 10% reduction in computing time and no significant difference in results.

C. Component Studies

Tornado depressurization can produce back flow (negative flow) when applied to the supply side of a blower and outrunning flow (positive flow and

Fig. 3. Blower Characteristics Representation.

negative head) when applied to the discharge side. Little is known about blowers operating in these regions, so we made a literature search and contacted several blower manufacturers. The literature search was unproductive, and opinions, but no data, were obtained from the manufacturers. Parameter studies were then conducted on a test case ventilation system to determine the sensitivity of system response to varying the slope of the blower characteristic curve in the back flow region. Table IV summarized the results for the three different slopes shown in Fig. 4. The perturbation was a Region I tornado applied to the suction side of the supply blower. The greater slope of Case III dramatically reduces the tornado effect on the system. The times to peak flow were the same in all three cases and were therefore omitted for this comparison.

Surface effect ships experience back flow in their lift fans when traversing heavy seas. Since the fans are similar to those used in ventilation systems, the manufacturers and test organizations

TABLE IV.
RESULTS FROM BACK FLOW TRIALS

Case	Maximum Flow (cfm)	Minimum Flow (cfm)
I	2368	-7134
II	2769	-8498
III	1270	-3558

Fig. 4. Blower Back Flow Trials.

were contacted regarding information they might have on this phenomenon. Figure 5 illustrates a typical test for these fans. Note the steep slope in the backflow region. The flow coefficient and head coefficient are defined respectively as

$$\text{Flow coefficient } \phi = Q / \pi D_o^2 \omega (\pi D_o N / 60), \text{ and (1)}$$

$$\text{Head coefficient } \psi = P_t / \rho (\pi D_o N / 60)^2, \quad (2)$$

where

Q = volumetric flow rate through one fan inlet (one-half the flow of a double entry), ft^3/s

D_o = impeller tip diameter, ft.

ω = impeller tip width ratio,

N = fan speed, rpm,

P_t = fan discharge total pressure (static + dynamic) that exists within the fan discharge duct and near the exit, lb/ft^2 , and

ρ = ambient density of the air, slugs/ft^3 .

Since D_o , ρ , ω , and N are assumed constant for our application, this curve is indicative of what might occur for a ventilation fan. Note the similarity of Fig. 5 to Case III of Fig. 4. Data were not

Fig. 5. Back Flow Characteristics.

available for the outrunning case; however, one designer felt that the normal curve could be extrapolated into the fourth quadrant to the extent of one cut-off head.

The information available is only qualitative, and more data are needed before the blowers can be accurately modeled in these abnormal flow regions. This information combined with worst case assumptions may give a designer guidelines for determining the effects of these abnormal operating conditions on system integrity.

The linear segmented approach used for the blowers may be used for other system components to provide more modeling flexibility. The affected areas of the program have been identified; this approach may be implemented where users determine that it is desirable.

D. System Solver Accuracy Studies

The algorithm used in TVENT employs an implicit nodal point relaxation technique to solve for the system pressures. This was checked with the Newton-Raphson and Gear Stiff Differential Equation methods early in the TVENT development. The accuracy obtained

by all three methods was essentially the same for the small test case ventilation system. Tests with larger and more complex systems such as might be found in practice were not made because of the difficulty in generalizing the latter two methods. Tests have been attempted with network solvers such as NET-2, but the nonlinear aspects of the problem are not suited to their capabilities. However, continuity checks can be made to determine the accuracy of the steady-state solution. Other checks will be attempted as other network solvers become available.

E. Friendly Users

We have invited the Bechtel Corporation (Gaithersburg, MD), Fluor Corporation (Irvine, CA), and the Ralph Parsons Corporation (Pasadena, CA) to become friendly users of TVENT. Being a friendly user of TVENT entails using the computer code and documentation in the analysis of new or existing ventilation system designs, and then providing LASL with comments and statistics that can improve the code and make it more acceptable for general use. All three companies have responded favorably to our invitation, and the Bechtel Corporation is already using the program.

IV. PHYSICAL MODELING

The feasibility of using a scale model to determine the behavior of a full-scale prototype ventilation system is being investigated.

The system shown in Fig. 6 was analyzed using the usual dimensional analysis and similitude techniques. Although this is a simple system when compared to an actual plant installation, it contains all of the elements essential for a complete understanding of system behavior.

Fig. 6. Simplified Ventilation System.

First, a desired dependent variable is expressed as a function of all quantities that affect system performance. Thus,

$$p_n = \phi(p_i, L, f, v, n, D, \rho, \mu, e, t), \quad (3)$$

in which

- p_n = pressure at any point in the system; a function of time,
- p_i = pressure at the inlet side; assumed to vary in a prescribed manner during tornado conditions (See Fig. 2),
- L = any linear dimension,
- f = any dimensionless friction factor; used to express pressure drop associated with flow through ducts, filters, dampers, etc.,
- v = flow velocity at any point in the system; volume flow rate ($Q\text{-m}^3/\text{s}$) or mass flow rate ($M\text{-kg/s}$) could be used in place of v if desired,
- n = blower rotational speed,
- D = blower size characterization; usually taken as impeller diameter,
- ρ = fluid density,
- μ = fluid viscosity,
- e = fluid bulk modulus, and
- t = time.

We must justify several simplifying assumptions before continuing with the dimensional analysis. Since fluid mechanics research indicates that in a system of this type, surface tension and gravitational forces are small compared to other forces, we have eliminated surface tension (σ) and the gravitational constant (g) from Eq. (3).^{*} Furthermore, the system is assumed to function isothermally or nearly so, and as a result the properties ρ , μ , and e are assumed to be constants. This assumption is based on results obtained from an analytical study using TVENT showing that the differences between isothermal and adiabatic conditions were negligible.²

All terms in Eq. (3) can be expressed in three fundamental dimensions: mass, M ; time, T ; and length, L .

* This is equivalent to neglecting the Weber Number ($\frac{\rho v^2 L}{\sigma}$) and the Froude Number ($\frac{v^2}{gL}$).

$$P_n = M L^{-1} T^{-2}$$

$$P_i = M L^{-1} T^{-2}$$

$$L = L$$

$$f = \text{dimensionless}$$

$$v = L T^{-1}$$

$$n = T^{-1}$$

$$D = L$$

$$\rho = M L^{-3}$$

$$\mu = M L^{-1} T^{-1}$$

$$e = M L^{-1} T^{-2}$$

$$t = T$$

According to the 'Pi' Theorem (3), Eq. (3) can be expressed in dimensionless terms. The number of dimensionless or 'Pi' terms required is computed as the number of quantities involved [11 in Eq. (3)] minus the number of fundamental dimensions in which they can be expressed. Hence,

$$\text{Number 'Pi' terms} = 11 - 3 = 8.$$

Therefore Eq. (3) can be rewritten as

$$\frac{P_n}{P_i} = \psi \left(f, \frac{tv}{L}, \frac{v}{nD}, \frac{P_n}{n^2 D^2 \rho}, \frac{v^2}{\rho e}, \frac{P_n}{\rho v^2}, \rho \frac{vL}{\mu} \right). \quad (4)$$

For convenience these dimensionless terms are assigned 'Pi' numbers as follows:

* These 'Pi' terms are in the form most often used in fluid mechanics work. π_4 and π_5 are the terms used to define 'homologous' or 'similar' pumps and blowers. π_6 is the Cauchy number, π_8 is the Reynolds number, and π_7 is the ratio of pressure forces to inertia forces.

$$\pi_1 = P_n/P_i,$$

$$\pi_2 = f,$$

$$\pi_3 = tv/L,$$

$$\pi_4 = v/nD,$$

$$\pi_5 = P_n/n^2 D^2 \rho,$$

$$\pi_6 = \rho v^2/e,$$

$$\pi_7 = P_n/\rho v^2, \text{ and}$$

$$\pi_8 = \rho vL/\mu.$$

From similitude theory³ we know that a true model must be designed, constructed, and operated so that every 'Pi' term in the model (m) system is equal to the equivalent 'Pi' term in the full scale or prototype (p) system.

That is,

$$\pi_{1m} = \pi_{1p},$$

$$\pi_{2m} = \pi_{2p},$$

etc.

These required identities determine how the model will be designed and operated and how the results will be scaled. Since the most practical approach will be to use the same fluid (air) in both the model and the prototype, these required identities should be solved for the case where

$$\rho_m = \rho_p,$$

$$e_m = e_p,$$

$$\text{and } \mu_m = \mu_p.$$

Unfortunately, with these three requirements the required 'Pi' term identities can not be satisfied. Therefore, the required identities will be solved requiring only that

$$\rho_m = \rho_p, \quad (5)$$

$$\text{and } c_m = c_p. \quad (6)$$

Defining a length scale (N_x) as any prototype linear dimension divided by the similar model linear dimension, i.e., $N_x = \ell_p / \ell_m$, and substituting Eqs.

(5) and (6) into $\pi_{6m} = \pi_{6p}$ we obtain

$$\frac{\rho_m v_m^2}{e_m} = \frac{\rho_p v_p^2}{c_p},$$

$$\frac{v_p}{v_m} = 1,$$

$$\text{or } N_x = 1, \quad (7)$$

where the velocity scale (N_x) is defined as

$$N_x = v_p / v_m.$$

From the required identity $\pi_{3m} = \pi_{3p}$ we obtain

$$N_t = N_x, \quad (8)$$

where the time scale (N_t) is defined as $N_t = t_p / t_m$.

From the required identity $\pi_{7m} = \pi_{7p}$, we obtain

$$N_p = N_x^2 = 1, \quad (9)$$

where the pressure scale (N_p) is defined as $N_p = p_p / p_m$. Finally, from $\pi_{8m} = \pi_{8p}$ we obtain

$$\frac{\mu_p}{\mu_m} = N_x.$$

This condition is not satisfied since we have chosen to use the same fluid in both the model and the prototype ($\mu_m = \mu_p$) and we are only interested in cases for which $N_x \neq 1$. Therefore, in the modeling being discussed, $\pi_{8m} \neq \pi_{8p}$; that is, the Reynolds numbers in the model and prototype will not be identical, and

unless some type of compensation is possible, the viscous effects will not be properly modeled.*

This is the usual circumstance in the design and operation of fluid system models, and this lack of complete similarity does not necessarily invalidate results obtained from scale models. However, the lack of complete similarity (the non-equality of Reynolds numbers in this case) should be recognized so that its effect is understood and compensated for in a rational manner. Several methods of compensating for lack of complete similarity can be used. These include the use of "compensating distortion and supplemental analyses and/or tests to determine a "prediction factor."**

During the coming quarters the necessary supplemental analysis will be conducted, additional tests will be planned, and an adequate model will be designed. This model will be designed around available filters and blowers and will be sized to be compatible with the test facilities being developed at New Mexico State University.

V. SUMMARY

Progress in using the computer code TVENT to analyze the response of the ICPP atmospheric protection system is described. Satisfactory agreement was found between TVENT results and field data for the ICPP at steady state. A tornado at the exhaust stack will result in a 70% flow increase through the HEPA filtering system. However, this represents only a 20% increase over the design flow of the filters.

In code development, several modifications and additions have been made to TVENT because of our experience in analyzing the ICPP. The code has been implemented to run on IBM and UNIVAC machines in

* The analysis could be repeated with $\rho_m = \rho_p$ and $\mu_m = \mu_p$. In this case the scales are found to be $N_x = 1/N_x$, $N_t = N_x^2$, $N_p = 1/N_x^2$, and the requirements that $e_p/e_m = 1/N_x^2$ cannot be satisfied if the same fluid is used in the model and prototype. This means that the Cauchy numbers in the model and prototype will not be identical and unless some type of compensation is possible the compressibility effects will not be properly scaled.

** For a complete discussion of distorted models see Murphy, Part II, Distorted Models.³

addition to CDC machines. Studies were carried out to improve the blower model for conditions of flow reversal and outrunning flow. Little blower response information exists in the literature, and we concluded that experimental data are needed to substantiate our modeling procedure. Our blower model response is similar to that found for blowers on surface effect ships in the back-flow region.

The initial investigation phases to determine the feasibility of scale-modeling ventilation systems are complete. The scaling laws that determine how a model is to be designed and operated, and how the results are scaled have been established. These laws, with the assumption that the same fluid (air) is used in both the model and prototype, have allowed the length, time, velocity, and pressure scales to be determined. The analysis indicated that complete similarity cannot be obtained between the model and the prototype. Distortion of the Reynolds number appears to offer the most practical approach. A distorted model is not unusual, but additional analysis

is needed to determine the effect of this distortion so that test results can be understood and compensated for in a rational manner.

REFERENCES

1. E. H. Markee, Jr., J. G. Beckerley, and K. E. Sanders, "Technical Basis for Interim Regional Tornado Criteria," WASH-1300 (May 1974).
2. G. A. Bennett, W. S. Gregory, and P. R. Smith, "Ventilation Systems Analysis During Tornado Conditions," Los Alamos Scientific Laboratory report LA-6210-PR (November 1975).
3. Glenn Murphy, Similitude in Engineering (Ronald Press Co., New York, 1950), pp. 28.
4. P. I. Nelson, "Final Safety Analysis Report for the Atmospheric Protection System," Allied Chemical Corporation report ICP-1082 (June 1976).
5. Norman Engineering Co., Los Angeles, architectural and engineering drawings for the atmospheric protection system, Drawings nos. 1255-CPP-series (May 1973).

APPENDIX A

ICPP DESCRIPTIVE INFORMATION

All information for modeling the ICPP ventilation system was obtained through P. I. Nelson, ICPP. The data obtained by way of conversations and correspondence are presented in this appendix. References 4 and 5 were also valuable sources of information and were made available to us by Mr. Nelson. Blower performance curves were given to us for the APS ventilation air exhaust blower and for the NO_x -containing process off-gas blower also housed in the APS.

The following data were obtained from a conversation with P. I. Nelson, ICPP, during our second visit to the site.

- o A performance for the APS exhaust blowers
- o A performance curve for the NO_x -containing process off-gas system in the APS
- o Facility volumes:
 - waste calcining 300 000 cf
 - analytical labs 660 000 cf
 - fuel processing 288 000 cf
 - cells 288 000 cf
 - corridors 712 000 cf

o Miscellaneous information

The vacuum at the entrance to the APS is controlled by dampers at the inlets of the exhaust blowers.

The waste calcining facility has both a supply and exhaust blower.

The flows in the waste calcining and waste treatment facilities are 11 000 and 21 000 cfm, respectively (confirming flows shown in FSAR).

We confirmed that most of the ventilation air going to the analytical labs is discharged directly to the environment (as shown on flow sheet).

Our modeling of the ICPP was generally confirmed.

Pressure and flow information for the various information for the various portions of the Atmospheric Protection System was obtained by letter from P. I. Nelson dated March 22, 1977 and is presented in Table A-I.

TABLE A-1
ICPP TECHNICAL INFORMATION

<u>Instrument</u>	<u>Description</u>	Two Exhaust Fans	One Exhaust Fan	
		<u>Late 1975</u>	<u>Late 1976, Jan. 1977</u>	
FR-1	Ventilation Flow (CFM)	105 000	80 000	78 000
PIC-11	Vacuum (in. H ₂ O)	1.6	0.5	0.6
PdR-16	Pressure Differential (in. H ₂ O)	1.8	1.4	1.4
PdR-17	Pressure Differential (in. H ₂ O)	2.2	1.6	1.4
PdR-53	Vacuum (in. H ₂ O)	5.0	3.7	3.3
PdI 1-26	Average Pressure Differential of HEPA Caissons (in. H ₂ O)	0.7	0.4	0.4

Blower (fan) information obtained by telephone
from P. I. Nelson on March 17, 1977.

Model 5102
Motor W
440V 13.5A
1165 rpm

Main supply blowers housed in Building 606 (2)

1. Manufacturer - Westinghouse
Style - 33k-1011-9A23493
Design - SV10DWCF
60 hp motor
440V and 72.5A
1800 rpm
Code G
Cap. 90 000 cfm (4900 ft)
Size 1255V

2. Manufacturer - Westinghouse
Style - 32-A-9985-9A-23492
Design - 10AS-CL1

Waste Calcining blowers housed in Bldg. 633

1. Supply blower
Manufacturer - American Blower Co.,
Los Angeles
13200 cfm
Type - 2S18
Catalog No. 2-BP90-7.4-13.6
2. Exhaust blower
Manufacturer - Joy Manufacturing Co.
Model No. V1000-535
11000 CFM
Serial No. SF-8482

Waste Treatment blower housed in Bldg. 604

Manufacturer - Westinghouse
Size 135
Style - 9A-23704
Design - IDAKR3

APPENDIX B

LIST OF INPUT DATA

TVENT JAN. 77 LASL

LIST OF INPUT DATA

	10	20	30	40	50	60	70	80
123456789012345678901234567890123456789012345678901234567890								
1**								
2**	ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS							
3**								
4**	RUN CONTROL I							
5**	.1	15.	50					
6**	PRINT/PLOT CONTROL							
7**	3							
8**	FRAMES							
9**	1	15			10000.			
10**	2	87	92		10000.			
11**	1	13			200000.			
12**	RUN CONTROL II							
13**	2000 P							
14**	BOUNDARY CONTROL							
15**	2 8							
16**	GEOMETRY AND COMP CONTROL							
17**	93	65	9	9	8			
18**	BRANCH DATA							
19#	14	14	154230.		V		9.197E-08	
20#	16	14	164230.		V		9.197E-08	
21#	18	14	174230.		V		9.197E-08	
22#	20	14	184230.		V		9.197E-08	
23#	22	14	194230.		V		9.197E-08	
24#	24	14	204230.		V		9.197E-08	
25#	26	14	214230.		V		9.197E-08	
26#	28	14	224230.		V		9.197E-08	
27#	30	14	234230.		V		9.197E-08	
28#	32	14	244230.		V		9.197E-08	
29#	34	14	254230.		V		9.197E-08	
30#	36	14	264230.		V		9.197E-08	
31#	38	14	274230.		V		9.197E-08	
32#	40	14	284230.		V		9.197E-08	
33#	42	14	294230.		V		9.197E-08	
34#	44	14	304230.		V		9.197E-08	
35#	46	14	314230.		V		9.197E-08	
36#	48	14	324230.		V		9.197E-08	
37#	50	14	334230.		V		9.197E-08	
38#	52	14	344230.		V		9.197E-08	
39#	54	14	354230.		V		9.197E-08	
40#	56	14	364230.		V		9.197E-08	
41#	58	14	374230.		V		9.197E-08	
42#	60	14	384230.		V		9.197E-08	
43#	62	14	394230.		V		9.197E-08	
44#	64	14	404230.		V		9.197E-08	
45#	15	15	414230.		F		1.733E-04	
46#	17	16	414230.		F		1.733E-04	
47#	19	17	414230.		F		1.733E-04	
48#	21	18	414230.		F		1.733E-04	
49#	23	19	414230.		F		1.733E-04	
50#	25	20	414230.		F		1.733E-04	
51#	27	21	414230.		F		1.733E-04	
52#	29	22	414230.		F		1.733E-04	
53#	31	23	414230.		F		1.733E-04	
54#	33	24	414230.		F		1.733E-04	
55#	35	25	414230.		F		1.733E-04	

L I S T O F I N P U T D A T A

	10	20	30	40	50	60	70	80
1234567890123456789012345678901234567890123456789012345678901234567890								
56#	37	26	414200.		F		1.733E-04	
57#	39	27	414230.		F		1.733E-04	
58#	41	28	414230.		F		1.733E-04	
59#	43	29	414230.		F		1.733E-04	
60#	45	30	414230.		F		1.733E-04	
61#	47	31	414230.		F		1.733E-04	
62#	49	32	414230.		F		1.733E-04	
63#	51	33	414230.		F		1.733E-04	
64#	53	34	414230.		F		1.733E-04	
65#	55	35	414230.		F		1.733E-04	
66#	57	36	414230.		F		1.733E-04	
67#	59	37	414230.		F		1.733E-04	
68#	61	38	414230.		F		1.733E-04	
69#	63	39	414230.		F		1.733E-04	
70#	65	40	414230.		F		1.733E-04	
71#	66	41	42110000.		D		4.006E-12	
72#	67	42	43		V		4.148E-09	
73#	68	42	44		V		4.148E-09	
74#	1	46	4065000.		B			
75#	2	1	50		V		1.126E-10	
76#	3	3	455000.		V		3.847E-07	
77#	4	50	5		V		4.478E-10	
78#	5	5	978000.		D		1.782E-10	
79#	6	6	721000.		V		3.086E-09	
80#	7	7	818000.		B			
81#	82	8	5421000.		V		1.247E-09	
82#	8	54	921000.		D		1.247E-09	
83#	9	10	1111000.		V		1.859E-08	
84#	10	11	1211000.		B			
85#	11	53	911000.		D		6.901E-08	
86#	12	9	13110000.		V		4.006E-12	
87#	13	13	14110000.		F		1.772E-05	
88#	69	43	4556000.		B			
89#	70	44	4556000.		B			
90#	71	45	46		D		5.510E-11	
91#	72	47	48		V		9.420E-11	
92#	73	48	4980000.		B			
93#	74	49	1		V		5.030E-12	
94#	75	1	3		V		2.626E-10	
95#	76	2	3		V		1.504E-09	
96#	77	1	2		V		3.502E-10	
97#	78	2	50		V		1.166E-09	
98#	79	4	5165500.		B			
99#	80	12	5211000.		V		8.264E-09	
100#	81	52	5311000.		B			
101#	83	55	56 50.		F		1.000E-02	
102#	84	56	57 50.		V		3.600E-04	
103#	85	57	58 50.		F		1.000E-02	
104#	86	58	59 50.		B			
105#	87	59	42 50.		D		8.000E-05	
106#	88	60	614000.		F		2.000E-04	
107#	89	61	624000.		V		6.250E-08	
108#	90	62	634000.		F		2.500E-04	
109#	91	63	644000.		B			
110#	92	64	454000.		D		1.000E-08	
111#	93	65	517500.		V		6.922E-09	
112##	BOUNDARY CARDS							
113#	55 -10.							
114#	60 -32.344							
115#	6							
116#	10							
117#	51							
118#	65							
119#	47							
120#	46							

LIST OF INPUT DATA

	10	20	30	40	50	60	70	80
1234567890123456789012345678901234567890123456789012345678901234567890								
121** TIME FUNCTIONS								
122# 1 5								
123#0. 0. 2.5 -41.5335 6.5 -41.5335								
124#9.0 0. 15.								
125# 2 6								
126#0. 0. 8.5 0. 11. -41.5335								
127#15. -41.5335 17.5 0. 25.								
128** ROOM DATA								
129# 52 100. 100. 20.								
130# 2 100. 100. 22.								
131# 3 100. 100. 14.								
132# 5 100. 100. 100.								
133# 12 100. 100. 10.								
134# 8 100. 100. 5.								
135# 50 100. 100. 40.								
136# 42 10. 10. 100.								
137# 45 10. 10. 250.								
138** BLOWER DATA								
139# 8 6								
140#-1000. 47.3 0. 37.5 2000. 42.								
141#3650. 40. 6250. 24. 8700.								
142# 7 4								
143#-20. 12.839 0. 9. 41.5 8.062								
144#83.5 0.								
145# 6 6								
146#-2000. 17.65 0.0 10. 4000. 11.5								
147#8000. 10.5 12000. 6.5 13700.								
148# 1 6								
149#-20000. 4.28 0.0 2.95 33254. 3.29								
150#69066. 2.951 86972. 2.39 122784.								
151# 2 2								
152#65494. 10. 65500.								
153# 3 4								
154#-10000. 1.868 0.0 1.03 34865. .75								
155#43830.								
156# 4 5								
157#-2000. 4.333 0.0 3. 7880. 3.5								
158#13000. 2. 16000.								
159# 5 6								
160#-20000. 25. 6. 17. 33000. 19.2								
161#55000. 17.7 75000. 13.6 109000. 0.								
162** PRESSURES								
163# 1.38 1.15 .753 -15. -6.69								
164# 0.00 -1.4 -.42 -1.6 0.00								
165# -2.2 -2.4 -1.7 -3.5 -5.0								
166# -5.0 -5.0 -5.0 -5.0 -5.0								
167# -5.0 -5.0 -5.0 -5.0 -5.0								
168# -5.0 -5.0 -5.0 -5.0 -5.0								
169# -5.0 -5.0 -5.0 -5.0 -5.0								
170# -5.0 -5.0 -5.0 -5.0 -5.0								
171# -5.7 -5.8 -17. -17. .658								
172# 0.00 0.00 -1.4 1.45 1.06								
173# 0.00 -1.76 6.73 -1.1 -10.								
174# -10. -11. -12. -5.6 -34.								
175# -33. -34. -35. .839								

APPENDIX C

ICPP VENTILATION - NODAL PRESSURES AND BRANCH FLOWS FOR NORMAL OPERATING CONDITIONS

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

NODAL PRESSURES										TIME = 0.
0	1	2	3	4	5	6	7	8	9	
0	1.37750	1.15993	.75005	-15.60700	-.70600	0.	-1.30790	-.52815	-1.65090	
10	0.	-.25570	.24007	-1.69510	-3.55500	-.05000	-.05000	-.05000	-.05000	
20	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	
30	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	
40	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	-.05000	
50	1.05010	0.	-.70625	6.72250	-1.00950	10.50500	-11.02300	-11.02000	-5.59450	
60	-32.34000	-33.10600	-34.33100	-35.39700	.03056	0.				

BRANCH FLOWS										TIME = 0.
0	1	2	3	4	5	6	7	8	9	
0	63939.0	53500.0	65207.0	62702.0	72003.0	21207.0	21217.0	21217.0	11015.0	
10	11015.0	11015.0	104900.0	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	
20	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	
30	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	
40	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	
50	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	
60	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	4037.3	4037.7	
70	52060.0	107100.0	127070.0	63939.0	127000.0	40001.0	104000.0	52060.0	52060.0	
80	11015.0	11015.0	21217.0	50.5	50.5	50.5	50.5	50.5	50.5	
90	4261.7	4261.7	4261.7	10102.0						

APPENDIX D

ICPP STEADY-STATE PRESSURES AND FLOWS FOR INDIVIDUAL COMPONENTS (BRANCHES)

DIFFERENTIAL PRESSURE ACROSS FILTERS								TIME = 0.
BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.	
13	1.000370	15	.699700	17	.699700	19	.699700	
21	.699700	23	.699700	25	.699700	27	.699700	
29	.699700	31	.699700	33	.699700	35	.699700	
37	.699700	39	.699700	41	.699700	43	.699700	
45	.699700	47	.699700	49	.699700	51	.699700	
53	.699700	55	.699700	57	.699700	59	.699700	
61	.699700	63	.699700	65	.699700	67	.699700	
85	.505000	88	.052000	90	1.066000	83	.505000	

FLOW THROUGH FILTERS								TIME = 0.
BRANCH	FLOW	BRANCH	FLOW	BRANCH	FLOW	BRANCH	FLOW	
13	100000.0	15	4037.3	17	4037.3	19	4037.3	
21	4037.3	23	4037.3	25	4037.3	27	4037.3	
29	4037.3	31	4037.3	33	4037.3	35	4037.3	
37	4037.3	39	4037.3	41	4037.3	43	4037.3	
45	4037.3	47	4037.3	49	4037.3	51	4037.3	
53	4037.3	55	4037.3	57	4037.3	59	4037.3	
61	4037.3	63	4037.3	65	4037.3	67	4037.3	
85	50.5	88	4261.7	90	4261.7	83	50.5	

DIFFERENTIAL PRESSURE ACROSS DAMPERS

TIME = 0.

BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.
2	.323400	3	16.357050	4	1.760500	6	1.307900
9	2.255700	12	.004200	14	1.499400	16	1.499400
18	1.409400	20	1.409400	22	1.499400	24	1.409400
26	1.409400	28	1.409400	30	1.499400	32	1.499400
34	1.409400	36	1.409400	38	1.499400	40	1.499400
42	1.409400	44	1.409400	46	1.499400	48	1.499400
50	1.409400	52	1.409400	54	1.499400	56	1.499400
58	1.409400	60	1.409400	62	1.499400	64	1.409400
67	11.417500	68	11.417500	72	1.500300	74	.081000
75	.627450	76	.400050	77	.226000	78	.096000
80	1.002720	82	.561350	84	.918000	89	1.135000
93	.706900						

PRESSURE RISE ACROSS BLOWER

TIME = 0.

BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.
1	2.999600	7	.859750	10	2.096170	69	17.872930
70	17.872930	73	2.999600	79	15.607000	81	7.484750
86	6.333500	91	36.235560				

PRESSURE DROP IN DUCT

TIME = 0.

BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.	BRANCH	D. P.
5	.904500	8	.561400	11	8.373000	64	.044000
71	.656930	87	.204000	92	.181630		

DIFFERENTIAL PRESSURE BETWEEN ROOMS

TIME = 0.

NODE	ROOM	1	2	3	4	5	6	7	8	9
52	1	0.								
2	2	1.41315	0.							
3	3	1.51730	.40005	0.						
5	4	.05505	-1.05730	-1.45645	0.					
12	5	1.00272	-.91043	-.50950	.90687	0.				
8	6	.23410	-1.67005	-1.27020	.17025	-.76062	0.			
50	7	1.41635	-.09600	.30405	1.76050	.81303	1.58225	0.		
42	8	-5.03625	-6.94940	-6.50055	-5.00210	-6.03097	-5.27035	-6.05260	0.	
45	9	1.41910	-.49397	-.09312	1.36333	.41046	1.18500	-.39717	6.45543	0.

APPENDIX E

TVENT COMPUTER-GENERATED PLOTS

Flow-vs-time computer-generated plots for the APS filter components are presented for each of the five possible tornado locations (Figs. E-1 through E-10). The maximum or minimum values of flow shown on these plots were obtained by rerunning the

solution to get printed output for the critical time associated with the maximum effect from the tornado transient. The prefilter is branch No. 13 and the HEPA caisson, branch No. 15. Each caisson contains four HEPA's connected in parallel.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 3 FLOW BRANCH NOS= 13
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

Fig. E-1. Flow through Prefilter for Tornado at Exhaust Stack.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 1 FLOW BRANCH NOS# 15
 ** CORRESPONDING CURVES# A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

100 PER CENT CORRESPONDS TO .1000E+05

Fig. E-2. Flow through HEPA Caisson for Tornado at Exhaust Stack.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 3 FLOW BRANCH NOS= 13
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

Fig. E-3. Flow through Prefilter for Tornado at Main Supply.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 1 FLOW BRANCH NOS= 15
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

Fig. E-4. Flow through HEPA Caisson for Tornado at Main Supply.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 3 FLOW BRANCH NOS* 13
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

100 PER CENT CORRESPONDS TO .2800E+06

Fig. E-5. Flow through Prefilter for Tornado at Analytical Labs Roof.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS.

***FRAME 1 FLOW BRANCH NOS= 15
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

100 PER CENT CORRESPONDS TO .1000E+05

Fig. E-6. Flow through HEPA Caisson for Tornado at Analytical Labs Roof.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 3 FLOW BRANCH NOS= 13
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

Fig. E-7. Flow through Prefilter for Tornado at Waste Treatment Facility.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

***FRAME 1 FLOW BRANCH NOS= 15
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

Fig. E-8. Flow through HEPA Caisson for Tornado at Waste Treatment Facility.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

**FRAME 3 FLOW BRANCH NOS= 13
 ** CORRESPONDING CURVES= A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

100 PER CENT CORRESPONDS TO .200RE+06

Fig. E-9. Flow through Prefilter for Tornado at Waste Calcining Facility.

ICPP VENTILATION-AIR AND PROCESS OFF-GAS SYSTEMS

FRAME 1 FLOW BRANCH NOS 15
 ** CORRESPONDING CURVES A
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

100 PER CENT CORRESPONDS TO .1000E+05

Fig. E-10. Flow through HEPA Caisson for Tornado at Waste Calcining Facility.

ICPP VENTILATION-AIR AND PRESS OFF-GAS SYSTEMS

***FRAME 2 FLOW BRANCH NOS= 87 92
 ** CORRESPONDING CURVES= B
 ** X CORRESPONDS TO MULTIPLE CURVES AT POINT

FLOW-TIME CURVES FOR AIR AND PROCESS
 OFF-GAS SYSTEMS WITH TORNADO AT EXHAUST STACK

TVENT OVERLAY STRUCTURE

APPENDIX G