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The Underground Main Fan Study at the Waste Isolation Pilot Plant

Kirk H. McDaniel[1], K.M. (Chris) Chmura[2], Keith G. Wallace[3]
[1]Senior Engineer, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad NM; [2]Manager, Mine Engineering, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM; [3]Vice President, Mine Ventilation Services, Inc., Fresno, CA.

ABSTRACT

The Waste Isolation Pilot Plant (WIPP) performed a feasibility analysis for the purpose of either modifying, supplementing, or replacing its two main mine fans. The WIPP, located near Carlsbad, New Mexico, is a U.S. Department of Energy (DOE) facility designed to demonstrate the permanent, safe disposal of U.S. defense-generated transuranic waste in a deep bedded salt deposit.

Since the centrifugal fans were installed in 1988, multiple operational and performance concerns have been identified. A comprehensive engineering study was conducted in 1995 to: 1) Qualify and quantify operational concerns, 2) Evaluate possible alternatives, and 3) Recommend an optimum solution.

Multiple system modification and/or replacement scenarios were evaluated with associated cost estimates developed. The study considered replacement with either centrifugal or axial fans. Multiple fan duties are required at the WIPP. Therefore, Variable Frequency Drives and Inlet Vane Controls (IVC) were investigated for centrifugal fans. In-flight adjustable blades were investigated for axial fans.

The study indicated that replacing the existing system with two double-width, double-inlet centrifugal fans equipped with IVCs was the best choice. This alternative provided the most desirable combination of: 1) ensuring the required operational readiness, and 2) improving system performance. The WIPP is currently planning to replace the first fan in 1997.

OVERVIEW OF THE WASTE ISOLATION PILOT PLANT

The Waste Isolation Pilot Plant (WIPP) is designed to permanently dispose of transuranic radioactive waste left from the research and production of nuclear weapons. The WIPP is located in southeastern New Mexico 43 kilometers (26 miles) east of Carlsbad. Project facilities include disposal rooms excavated in an ancient (approximately 250 million years old), stable salt formation 660 m (2150 ft) underground. Transuranic waste consists of clothing, tools, rags, and other such items contaminated with trace amounts of radioactive elements, mostly plutonium.

DESCRIPTION OF THE VENTILATION SYSTEM

Ventilation of the underground facility at WIPP is accomplished with four main ventilation splits called the north area, mining area, waste storage area, and the waste shaft station. In order to minimize occupational exposure of underground personnel to radiation and radioactive materials, the facility is designed and constructed based on the "As Low As Reasonably Achievable" (ALARA) concept. This concept resulted in a design where the nuclear waste transportation and storage areas are separated from the mining

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and non-radioactive experimental areas. The ventilation system is also designed such that air leakage is from the mining and north areas into the waste storage areas. Furthermore, radiation detectors are strategically located throughout the underground, and a contingent exhaust filtration system is installed on surface to minimize the unlikely release of radiation to the environment.

The underground facility is accessed and ventilated through four vertical shafts, three of which supply intake air, and the fourth acts as a common exhaust. Ventilation through the facility is provided by running either one or both 450 kW (600 hp) centrifugal main fans. During concurrent mining and waste handling operations, both fans operate in parallel (Normal Ventilation Mode) to provide 230 m^3/s (490,000 acfm). When either mining or waste emplacement is not taking place, the ventilation demand is decreased and only one main fan is operated (Alternate Ventilation Mode) resulting in an airflow of 140 m^3/s (300,000 acfm). In the unlikely event of an underground radioactive release, the ventilation system is shifted to a filtration mode. In Filtration Mode, the air flow is reduced to 28 m^3/s (60,000 acfm). This airflow is achieved by turning off the main fans and starting one of three 175 kW (235 hp) centrifugal stand-by filtration fans. A series of isolation dampers diverts the air through the High Efficiency Particulate Air (HEPA) filters.

THE MAIN FAN STUDY

The main fans were installed in 1988 to supply the WIPP facility with the capability of conducting simultaneous mining and waste emplacement activities. Their design was based primarily on: 1) accepted ventilation engineering principles, 2) the best available data and calculations from the ventilation system, 3) current knowledge of the underground environment, and 4) the design parameters of interfacing WIPP structures. Field measured data collected since then has documented that some of the original design assumptions did not accurately reflect real operating conditions. The result is that the main fan system does not operate well in the environment for which is was originally designed. These factors have contributed to multiple operational and performance concerns. The key concerns associated with the performance of the main fan system include:

1) premature failure of a fan wheel.
2) 7 to 8 years expected operation between major overhauls.
3) demonstrated poor ability to endure weathering in a corrosive salt-and-moisture environment.
4) unequal power consumption between fans.
5) Operational Readiness (OR) of 65% in Normal Ventilation Mode.
6) fan static efficiency of 55% in Normal Ventilation Mode, as compared to the original design efficiency requirement of 85%.
7) concern that the present system may not effectively support simultaneous mining and waste emplacement at fully operational levels.
8) no system redundancy in Normal Ventilation Mode.

From August 1994 through July 1995, the Mine Engineering Group of WIPP/ Westinghouse Electric Co. conducted a comprehensive engineering study of the underground ventilation main fan system. This study was undertaken in an attempt to: 1) qualify and quantify the operational difficulties experienced with the fans since their installation, 2) evaluate possible alternatives, and 3) recommend a solution that would optimize the main fan configuration.

The current fan system was thoroughly evaluated as part of the study. The identified deficiencies were fully investigated through field inspection and testing of the fans. Engineering calculations, maintenance records, and historical operational availability data on the fans were also evaluated. The current physical condition and performance characteristics were documented, as well as alternatives for repairing and/or improving the fans.

The scenario of keeping the existing fans and overhauling them on a periodic basis became the base case for the study. A series of system modification and/or replacement alternatives which would satisfy the operational needs of the facility were developed. Each system was judged against predetermined acceptance criteria of: 1) capital cost, 2) power consumption savings, and 3) OR.

The alternatives which passed these criteria were augmented by supplementary Life Cycle Cost Analyses for the purpose of obtaining In House Energy Management (IHEM) funding for the project. IHEM is a U.S. Department of Energy program which finances projects based on their energy cost savings. These alternatives were compared against the base case.

The most favorable scenarios were evaluated to determine Present Value, Net Savings, Power Savings, Simple Payback, Savings-to-Investment Ratio, and Adjusted Internal Rate of Return for both ten and twenty-five year operational periods (these concepts are not discussed in this paper). In addition, they were evaluated to consider the flexibility and possible operational impacts associated with the alternative(s). The following section discusses the evaluation process for the main fan study.

EVALUATION OF EXISTING FANS AND CONCLUSIONS

The first step in the main fan study involved a thorough evaluation of both existing fans, including a review of their historical performance data. This information was obtained from field testing, review of operator logs and lockout/tagout records, and a review of the fans' design and performance characteristics.

The evaluation lead to the following conclusions: 1) stated concerns and field observations were confirmed, and 2) the existing fans could not be sufficiently modified to adequately address all of the concerns. The results of this evaluation were summarized in the report called "Underground Main Ventilation Fan Study Report" - May 1995. In order to secure the required performance of the main fan system, it was recommended to upgrade the existing system through implementation of one of the preferred scenarios.

EVALUATION CRITERIA AND METHODOLOGY

The evaluation methodology considered the capital cost, power consumption, and OR for each alternative. The scenarios considered for the system upgrade consisted of combinations of either replacing the two existing fans, adding a third fan, or repairing the existing fans. A comparative analysis was performed to eliminate alternatives from further consideration based on pass/fail selection criteria. Three pass/fail criteria were selected to reflect reasonable expectations of capital cost and operating characteristics. Figure 1 shows the logic sequence associated with the evaluation and screening of multiple fan scenarios using the pass/fail criteria. Options were considered valid if the estimated replacement cost did not exceed $1,300,000. This value was considered a reasonable cost which could be incurred without violating funding criteria for this type of project. Power consumption savings for each alternative had to be greater than 600,000 kWhr/yr (as compared to the existing fans). This value was considered a reasonable improvement in the power consumption as a benefit for replacing the fans.

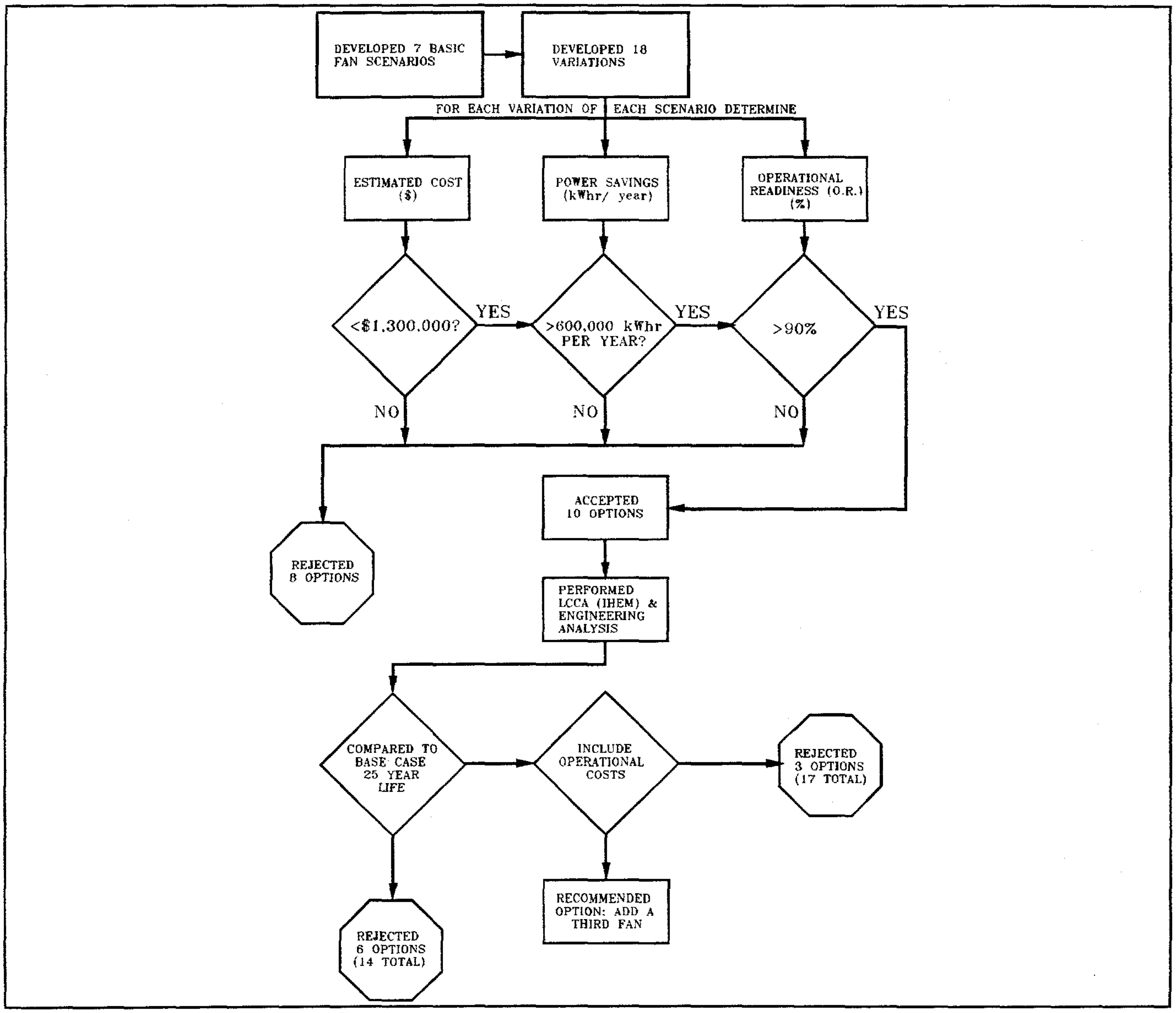

Figure 1. Evaluation Methodology Sequence

Table 1 shows a typical power consumption calculation. The OR requirement was set at 90%. This value was considered the minimum acceptable necessary to support the long term operational needs of the WIPP. Table 2 shows a typical fan OR calculation. A fan scenario was eliminated from further consideration if it failed any one of the three criteria. These criteria were used for initial screening to eliminate an unfavorable scenario before additional detailed analysis.

Table 1. Example of Fan Comparison Analyses

Base Case	Operating Mode	Fan Pressure (in. w.g.)	Airflow (cfm)	Fan Efficiency (%)	Predicted Power Consumption (kWhr/yr)	25 year Life Cycle Cost ($)
Centrifugal with IVCs	Alternate	4.3	330,000	37	2,571,415	
	Normal	7.3	490,000	55	2,669,935	
TOTAL					**5,241,354**	**12,704,740**

Alternatives Investigated	Mode of operation	Fan Pressure (in. w.g.)	Airflow (cfm)	Fan Eff. (%)	Predicted Power Consumption (kWhr/yr)	25 year Life Cycle Cost ($)	Annual Power Savings (kWhr/yr)	25 Year LCC Savings ($)	Payback (years)
Add Third Fan (New Fan w/IVC)	Alternate	4.5	330,000	42	2,255,046				
	Normal	8.5	245,000	83	824,996				
Original Fans	Alternate	4.3	330,000	37	431,650				
	Normal	7.3	245,000	55	1,069,230				
TOTAL					**4,580,621**	**8,939,677**	**660,430**	**3,765,063**	**10**
Replace Fans (two duty w/IVCs)	Alternate	4.8	330,000	56	2,131,474				
	Normal	10.5	490,000	83	2,018,281				
TOTAL					**4,419,755**	**8,957,710**	**1,091,596**	**3,747,030**	**12**

Table 2: Example of Operational Readiness Calculation.

Operational Readiness Calculation for Existing Fan:

Operating Options:

Fan	1	2	3	4
1	operating	operating	down	down
2	operating	down	operating	down
Normal *	yes	no	no	no
Alternate**	yes	yes	yes	no

* Normal Mode requires both fans operating

** Alternate Mode requires one of the two fans in operation

Probability of Operating:

Fan***	1	2	3	4
1	86.5	86.5	13.5	13.5
2	75.2	24.8	75.2	24.8
(1 x 2)	65.05%	21.45%	10.15%	3.35%

*** Historical data show fan 1 is available 86.5%, fan 2 at 75.2%.

Normal Mode Operational Readiness: 65.05%

Alternate Mode Operational Readiness: 96.65%

Operational Readiness Calculation for Adding a Third Fan

Operating Options:

Fan	1	2	3	4
1	operating	operating	down	down
2	operating	down	operating	down
3	operating	operating	operating	operating
Normal *	yes	yes	yes	no
Alternate**	yes	yes	yes	yes
Fan	5	6	7	8
1	operating	operating	down	down
2	operating	down	operating	down
3	down	down	down	down
Normal*	yes	no	no	no
Alternate**	yes	yes	yes	no

* Normal Mode requires two of three fans operating

** Alternate Mode requires one of the three fans in operation

Probability of Operating:

Fan*	1	2	3	4
1	86.5	86.5	13.5	13.5
2	75.2	24.8	75.2	24.8
3	90.0	90.0	90.0	90.0
(1 x 2 x 3)	58.54%	19.31%	9.14%	3.01%
Fan****	1	2	3	4
1	86.5	86.5	13.5	13.5
2	75.2	24.8	75.2	24.8
3	10.0	10.0	10.0	10.0
(1 x 2 x 3)	6.50%	2.15%	1.02%	0.33%

**** Assume new fans have an OR of 90% each.

Normal Mode Operational Readiness: 93.49%

Alternate Mode Operational Readiness: 99.67%

The study was conducted in the following sequence: 1) develop alternatives, 2) develop costs, 3) assess OR, and calculate power consumption, 4) eliminate unfavorable alternatives, 5) perform life cycle cost analyses, and 6) develop final system recommendation.

ALTERNATIVES ANALYZED

A total of seven fan configurations were considered as part of the study. They were:

1) Replace both existing fans with fans capable of supporting both Normal and Alternate modes of operation.
2) Add a third two- duty fan capable of both ventilation duties and keep the existing fans.
3) Add a third high duty fan capable of Normal Ventilation Mode and keep the existing fans for backup.
4) Add a third high duty fan capable of Normal Ventilation Mode and replace the existing fans.
5) Add a third low duty fan and replace the existing fans. The combination of any two fans in parallel would provide Normal Ventilation Mode, and any one fan could provide Alternate Ventilation Mode.
6) Add a third low duty centrifugal fan and keep the existing fans. The combination of any two fans in parallel would provide Normal Ventilation Mode, and any one fan could provide Alternate Ventilation Mode.
7) Replace one existing fan with a two-duty fan capable of both ventilation duty points, and keeping one of the existing fans.

Each of these alternatives was analyzed using centrifugal and axial vane fans (if the combination of operating fans in parallel was appropriate). To accommodate the two distinct fan duties, centrifugal fans with either Inlet Vane Controllers (IVCs) or Variable Frequency Drives (VFDs) were analyzed. In-flight adjustable blades were considered for axial fans. This resulted in a total of eighteen scenarios. For those alternatives which used the existing fans, the cost of needed repairs was estimated at $150,000 per fan every seven years.

INITIAL CONCLUSIONS

The initial fan study recommended as the preferred alternative replacement of the existing mine fans with two Double Width, Double Inlet (DWDI) centrifugal fans each capable of operating at both the Normal and Alternate ventilation modes and equipped with VFDs. A centrifugal fan system was selected because: 1) its energy efficiency is superior to the existing system, 2) preliminary life cycle cost analysis indicated that replacement of the fans is economically advantageous, and 3) the project appeared to have potential for IHEM funding. A similar fan system equipped with IVCs also satisfied all of the criteria; however, the lower efficiency associated with IVCs (as compared with VFDs) precluded the system from passing the IHEM acceptance criteria.

In addition to a concern about the ability of axial fans (whether equipped with in-flight adjustable blades or not) to endure the dynamic loads which can occur as the WIPP underground ventilation system shifts rapidly between operational modes, the initial high cost of axial fans capable of providing the required duties contributed in part to their elimination. Centrifugal fans, with their no-stall characteristics, provide a proven, and reliable technology for these conditions. Noise level was also of concern in that there are numerous offices in the vicinity of the main fans. Centrifugal fans, which generally operate at lower speeds, would have a greater chance of not exceeding permissible sound levels.

LIFE CYCLE COST ANALYSIS

Supplementary engineering analyses of the preferred scenarios were performed to satisfy the specific requirements of the IHEM application (IHEM requires that cost savings be derived from energy savings and that the project have a simple payback period of less than ten years).

To evaluate the cost effectiveness of each alternative, the Department of Commerce computer program Building Life-Cycle Cost (BLCC Version 4.2-95) was used. This program provides economic analysis of proposed capital investments that are expected to reduce long-term operation costs of buildings or building systems/components. Application of this program toward analysis of the alternative fan scenarios was appropriate. Life cycle cost analyses of all potential fan scenarios were generated and compared to the base case. The BLCC program uses a predetermined (internally programmed) escalation rate for future electric utility costs based on geographic location in the United States. This escalation accounts for (and assumes) common factors that influence electric utilities.

The result of the life cycle cost analysis showed that the use of VFDs resulted in a substantial increase in energy savings as compared to the existing system. However, low energy costs in southeast New Mexico (less than $0.045/kWhr), coupled with the relatively high capital cost of incorporating VFDs, resulted in an unacceptable project payback. This scenario would have saved approximately 43,000,000 kWhrs over 25 years, yet failed to save enough power costs to satisfy the required payback period. A comparison showed that a one cent (or 25%) increase in the cost of electricity (per kWhr) resulted in a decrease in the payback period of only 2 years. IHEM funding was eventually dropped from consideration in the study.

Final Life Cycle Cost Analyse were performed on the preferred alternatives. Table 1 also shows an example comparison analyses. Operational impacts associated with each scenario (which were not previously quantified) were included into the analysis at this stage. Each scenario was affected by a base overtime cost (associated with the need to match mining activities with waste disposal activities at full facility throughput), plus overtime cost associated with the unavailability of two main fans to operate in Normal Mode. These costs were applied in the BLCC program in years 7 through 20 of the WIPP expected facility life. This represents the years which simultaneous mining and waste disposal operations is required at full facility throughput. In the worst OR scenario (maintaining the existing system), the OR component resulted in sufficient overtime to justify a second mining crew (at fully burdened costs). For scenarios with increasingly higher ORs, this additional cost became a relatively minor component compared to the base overtime. The addition of these operational considerations had a significant impact on the results of the LCCA.

FINAL CONCLUSIONS

The final conclusion of the fan study was to install one new single-duty fan of similar size to the existing fans, and to maintain the existing system. Any two fans in parallel would be capable of providing Normal Ventilation Mode, and any one fan would be capable of providing Alternate Ventilation Mode. The new fan system would be designed with a 25 year life and be suitable to endure weathering in a corrosive salt-and-moisture environment. The system would provide redundant fans available to achieve Normal

Ventilation Mode. The new fan would be run 100% of its available time in order to maximize the system efficiency and OR. The existing fans will be overhauled on a periodic basis depending on their operational utilization and rate of deterioration. The new system would provide the underground ventilation system with a volumetric efficiency of approximately 80 - 85% during normal mode, and 55 - 60% during alternate mode of operation. The OR for Normal Ventilation Mode would be increased from 65% to 96%. IVCs were ultimately chosen over VFDs because of capital cost considerations. The new system has a LCCA savings of $3,765,000 compared to the base case, and a discounted payback of approximately 10 years.

SUMMARY

The underground ventilation main fan study provided an opportunity to analyze multiple fan replacement scenarios on a comparative basis prior to making a final recommendation. The use of pass/fail criteria for capital cost, OR, and power consumption savings enabled unfavorable alternatives to be eliminated early in the process without completing extensive economic analysis on each, thus requiring less engineering effort for a more complete study. The use of the Building Life-Cycle Cost (BLCC Version 4.2-95) program allowed the more favorable alternatives to be analyzed and compared to the base case in order to understand the long term costs for each alternative. The result of this study is that a fan system was proposed which will support the operational needs of the underground facility, and provide a reasonable payback period while optimizing the use of existing site resources.

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