Cost Analysis of Portable Refuge Chambers

Summary

A cost analysis of refuge chambers from an industry perspective was conducted. This analysis quantified costs for the purchase, installation, training, maintenance and inspection, and movement of refuge chambers. Benefits associated with the use of the refuge chamber were not evaluated in this analysis. Information to quantify costs was obtained from request for certification of emergency shelter documents submitted to the state of West Virginia by the manufacturers, from regulations for refuge chambers, and by contacting the manufacturers directly. A review of the documents submitted to the state of West Virginia and regulations for refuge chambers provided the bulk of the information, while contacting manufacturers had limited success (with only one manufacturer willing to provide information for use in this analysis.

To simplify the analysis, the refuge chamber costs were separated into three segments: 1) purchase, installation, and training, 2) maintenance and inspection, and 3) move. The purchase segment included cost for the purchase of the refuge chamber, its initial installation underground at the working face, and any safety training required for both initial training and any annual training required thereafter. Maintenance and inspection costs were estimated through the use of schedules of inspection provided by the manufacturers. The daily and monthly inspections were assumed to be performed by mine personnel, with all other inspections conducted by the manufacturer at an additional cost. The frequency of refuge chamber moves was determined by review the West Virginia refuge chamber regulations, and conducting calculations to determine frequency of move base upon typical underground coal mining production rates. Costs of mine personnel were based upon hourly wage rates from 2004.

Net present value calculations were performed on the quantified costs over a 10 year life span for the refuge chamber using a 9.5% discount rate. The 9.5% discount rate is based upon the cost of capital – the actual cost of financing money. This approach simplifies the selection of the discount rate. Results of the net present value calculations are presented in the following table:

	Present Worth Cost	Percent of Total Cost
Purchase cost	$80,000	23.4%
Installation	$700	0.2%
Training	$65,500	19.0%
Maintenance & Inspection cost	$25,400	7.4%
Moving costs	$169,600	50.0%
Total	**$341,200**	

As seen from the table, the cost of a single refuge chamber over its 10 year life span is approximately $341,000. This cost is significantly higher than the purchase cost as installation, training, maintenance and inspection, and moving costs were considered. These additional costs are associated with the refuge chamber and are necessary in order to properly implement the refuge chamber in a mining environment. Moving costs were a significant portion of the refuge chamber cost – comprising 50% of the cost over the 10 life span. Purchase costs made up 23% of the costs with training being 19%. Installation and maintenance and inspection were minor components of the total cost.

Sensitivity analysis of the refuge chamber costs was conducted and showed that changes in the required number of moves can have a significant impact on its cost. The amount of time required for safety training also had a significant impact, while not as large as the moving costs. Maintenance and inspection had the smallest impact on refuge chamber costs. Changes in the discount rate also had a significant effect on the refuge chamber cost. However, selecting an alternative discount rate to use for this cost analysis is best left to the discretion of industry, as selection can involve the determination of opportunity cost, cost of risk, and inflationary cost into the discount rate, and is dependent upon the individual mining company's operating philosophy. From the sensitivity analysis results, if all the segments (purchase, maintenance and inspection, and move) had the lower costs used in the sensitivity analysis, the cost of one refuge chamber could possibly be $154,250. Conversely, if the higher costs from the sensitivity analysis prevailed the costs could possibly be $564,000 compared to the current single refuge chamber cost of $341,200 as calculated in this analysis.

General Assumptions

This analysis reviews the cost of refuge chambers from an industry perspective. Many of the assumptions used in this analysis are based upon guidelines found in the request for certification of emergency shelter documents submitted to the state of West Virginia by the manufacturers. Regulations also provided guidance. However, guidance from the regulations was limited as the only current regulations on the use of the refuge chamber are from the State of West Virginia. Additional information was obtained by contacting the refuge chamber manufacturers. However, only one manufacturer was willing to provide additional information for this analysis.

To conduct a cost analysis of the refuge chambers, the implementation of the chambers must be reviewed. Figure 1 outlines a flowchart which delineates the implementation process of a refuge chamber. The steps to be followed are to purchase the refuge chamber, install the chamber in the mine, train the miners to use the chamber, maintain the chamber throughout its expected life, and move the chamber to keep it maintained within an acceptable distance from the working face. Therefore, this analysis evaluates the refuge chamber cost in three distinct segments: purchase, maintenance, and move. It also only evaluates the cost of one refuge chamber, whereby the mine operator can use the results of this analysis for the conditions at their specific mining operation and apply it to their refuge chamber requirements. Because attempting to conduct a cost analysis for every underground coal mining scenario would be impracticable.

This analysis is conducted for underground coal mines using the assumption that the mining operation runs 24 hours per day, 365 days per year. Another important assumption concerns the

useful life of the refuge chamber. From discussions with manufacturers, the useful life of the chamber is variable, ranging from 5 to 15 years or more depending upon the environment the chamber is installed. A more corrosive environment due to mine acid drainage would decrease the life of the chamber. This analysis evaluated the refuge chamber over a 10 year life span, at the end of which a new chamber would have to be purchased.

The lack of guidance of operation and maintenance of refuge chambers after they have been used during a mine disaster is currently not available. It is beyond the scope of this evaluation to hypothesize upon the use of refuge chambers after the occurrence of a mine disaster. Therefore, the focus of this analysis is on the purchase, installation, maintenance, and movement of the refuge chambers without the occurrence of any mine disasters. It is apparent that the occurrence of a mine disaster would incur costs above the baseline cost evaluated in this study.

The following analysis is an attempt to quantify all costs that may be encountered when implementing a refuge chamber program in an underground coal mine. Only costs related to the implementation of refuge chambers were evaluated in this analysis; no benefits which may accrue from the use of these chambers were included. This analysis was conducted using the employer's perspective for the determination of the costs. The company perspective was chosen because companies will most likely bear these costs in the future.

The information used in this analysis is the best available information and may not be representative of all possible cases for refuge chamber implementation. The information is used for evaluation purposes only and may not necessarily be comparable to actual situations. The results of this analysis should not be construed to be predictive of what may occur when a refuge chamber is put into operation. Although, every attempt was made to accurately quantify all pertinent costs, some cost information may not have been included or available, due to the varying nature of individual mining operations and unforeseen circumstances in refuge chamber implementation. The purpose of the analysis is to provide cost information which may be pertinent to refuge chamber implementation.

Purchase

The first step is to purchase the refuge chamber. This analysis evaluates the cost of ready-made portable refuge chambers. Permanent refuge chambers that can be built into the mine by the mining operations are not evaluated. There are many models of portable refuge chambers available and their purchase costs can vary from $45,000 to $140,000[1] (Skiles, et al., 2006). Additionally, different manufacturers have different options available to accommodate different mine characteristics throughout the United States at additional costs. Since these options were dependent upon the differing mine characteristics, their costs were not included in this analysis. In this cost analysis, the additional costs of installation and safety training are evaluated together with the purchase cost.

[1] Fernando, R., Draeger Safety, Inc., Personal Communication.

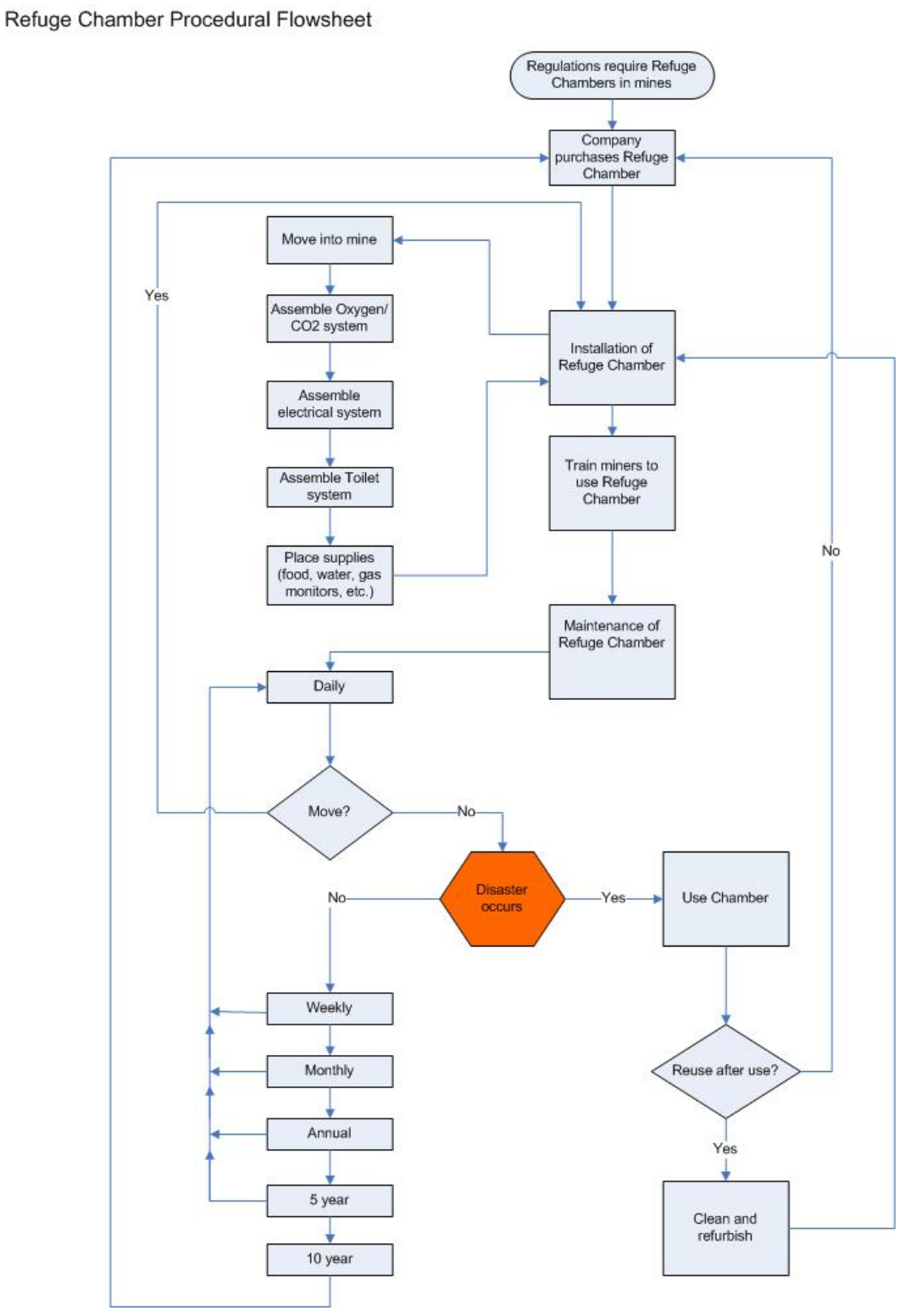

Figure 1. Flowsheet presenting steps for implementation of a portable refuge chamber.

The refuge chambers are generally self-contained, so installation is a relatively simple procedure of moving the chamber from the surface into the mine to the working face. Some manufacturers

will provide personnel to assist with the installation, while others may not. For this analysis, moving requires 3 mine personnel; a mechanic, an electrician, and a laborer. Their costs are listed in Table 1 under miscellaneous personnel. The fact that entrances to underground coal mines can vary from portals to shafts and the lack of documentation of data for moving the chambers into the mine; can make the cost determination of installation complicated. To simplify matters, the time required to move the chamber into the mine was estimated at 8 hours and no attempt was made to differentiate between the different types of entrances. Any equipment used for installation into the mine is assumed to already be at the mine site. Therefore, the cost of any equipment or material used in the chamber move are considered incidental to the mining operations.

Training costs are incurred once the refuge chamber is installed on-site. The initial training will require all mine personnel to be trained, which requires personnel costs to calculate the cost of training. However, the number of personnel working at a mining operation varies significantly from mine to mine (Leinhart, 2004). Therefore, this analysis focuses only on the personnel working at the mining section and does not include costs for salaried employees and other hourly support personnel (mechanics, electricians, etc.). It is recognized that inclusion of salaried employees and the support personnel would increase the training cost significantly. Table 1 shows the number of hourly personnel and their cost with benefits for a typical continuous miner group at a room and pillar mine (Stefanko, 1983) (Leinhart, 2004). A longwall system has different personnel classifications, but contains a similar number of personnel (approximately 7 employees) (Stefanko, 1983). Therefore the total hourly rate for personnel on a continuous miner group is used for all training activities for either type of mining; room and pillar or longwall.

Table 1. Personnel Costs

Personnel required for a continuous miner production group					
	Number	Hourly Wage	Benefits	Hourly Rate	Total Hourly Rate
Mine Forman	1	$33.00	44%	$47.52	$47.52
Continuous Miner Operator	1	$20.31	48%	$30.06	$30.06
Roof Bolter	2	$20.13	48%	$29.79	$59.58
Shuttle Car Operator	2	$19.96	48%	$29.54	$59.08
Laborer	1	$18.43	48%	$27.28	$27.28
Total	**7**				**$223.52**
Miscellaneous personnel required for refuge chamber installation and moves					
Mechanic	1	$20.41	48%	$30.21	$30.21
Electrician	1	$20.33	48%	$30.04	$30.04
Laborer	1	$18.43	48%	$27.28	$27.28
Total	**3**				**$87.53**

The number of personnel and their category for a continuous miner group are from Stefanko, 1983.
Wages and benefits of personnel are from Leinhart, 2004.

This initial training is anticipated to last 2 hours per session and will include a demonstration of the refuge chamber. Once the initial training has been completed, retraining will be required. No guidelines have been set for re-training. However, it has been recommended that the re-training occur during the required annual refresher training, if not more frequent. Currently, it is assumed that time can be allocated from the annual refresher training without compromising the content of the established training content at the mine site. Therefore, annual training costs for the refuge chamber are considered to be incidental to the annual refresher training. However, training will be required of all mine personnel whenever the refuge chamber is moved; in order to inform mine personnel of the new locations and any other considerations of the chamber at its new location. This training is anticipated to last 15 minutes, and will occur after every chamber move. The frequency of this training is based upon calculations completed in Appendix A, which are discussed later in the Move section. Appendix A shows the refuge chamber moves occurring every 6 days varying to every 9 days and up to every 20 days, depending upon mining type. For this analysis, the training will occur 5 times per month (based upon a move occurring every 6 days) and will include the personnel in the continuous miner group section list in Table 1. This listing shows the personnel for 1 shift, since it is assumed a mine works 24 hours per day, this listing must be multiplied by three – for each shift.

Maintenance

Once the refuge chamber has been purchased and installed, there are inspections and maintenance required at different intervals to ensure the refuge chamber is at a ready state. Generally, each manufacturer of refuge chambers maintains a schedule of maintenance/inspection which lists the maintenance requirements at each time period. The maintenance is separated into daily, monthly, semi-annual, annual, 3 year, 5 year, and 10 year inspections.

Almost all of the maintenance and inspections could be performed by the mining company. However, one manufacturer recommended that, considering their expertise, all inspections other than the daily and monthly inspections should be performed by them. They would perform these inspections and maintenance at an additional cost to the mining company. When evaluating the cost of the maintenance, this option was chosen as being the simpler solution for refuge chamber maintenance. Therefore, it was assumed that the mining company would perform the daily and monthly inspections and would be completed by the mine foreman. The cost for the daily inspections would be incidental to the mine foreman's current tasks and therefore, would not incur additional costs to the mining company. However, costs for the monthly inspections, as they are more detailed than the daily inspections, were estimated using 15 minutes as the duration of the inspection by the mine foreman.

The semi-annual, annual, 3 year, 5 year, and 10 year inspections would be performed by the manufacturer at a cost of $1,000 per visit plus any costs incurred to replace any items.[2] Therefore, there will be two manufacturer visits per year for the semi-annual and the annual inspections. It is assumed that the 3 year, 5 year, and 10 year inspections can occur during one of the semi-annual or annual inspections, thereby eliminating the cost for these inspections.

[2] Tatton, R., President, Mining Health and Safety Solutions, Personal Communication.

During the life of the portable refuge chamber, it is assumed that there are no malfunctions discovered during the inspections and that items are only replaced at the end of their useful lives. Costs of items that are replaced at scheduled intervals were obtained from equipment manufacturers and are listed in Table 2.

Table 2. Replaceable items for refuge chamber.

	Useful Life (years)	Replacement Cost
Oxygen	5	$2,500
Batteries	5	$2,500
CO_2 Scrubber Materials	5	$11,500
First Aid Kit	5	$1,000
Food & Water	5	$1,400
Total		**$18,900**

Costs and useful lives were obtained from Mining Health and Safety Solutions.

Moving

Periodically, the portable refuge chamber must be moved to maintain an acceptable distance away from the working face. There is limited guidance for moving portable refuge chambers. MSHA has regulations for underground metal and non-metal mines which state that refuge chambers must be within 30 minutes of a miner's workplace (CFR, 2007). Regulations that apply to coal mines are from the state of West Virginia. West Virginia regulations establish that the refuge chamber must be within 1,000 feet of the nearest working face in each working section (West Virginia, 2007).

Calculations for the number of times that a portable refuge chamber is required to be moved were based upon the West Virginia regulations. These calculations are shown in Appendix A. Figures 1, 2, and 3 show illustrations of a typical room and pillar 3 entry system, room and pillar 9 entry system, and longwall system, respectively. Calculations for the room and pillar 3 entry system show that the refuge chamber must be moved as the section advances approximately every 6 days. Similar calculations for a room and pillar 9 entry system show that the move must occur approximately every 9 days. For a longwall system, the chamber must be moved ahead of the longwall approximately every 20 days, as the shearer will advance toward the refuge chamber rather than away from the chamber as in the room and pillar systems. It should also be noted that due to the long panel widths of the shearer (varying from 500 ft. to 1,450 ft.) (Fiscor, 2007); a longwall system may require two refuge chambers. The results of these calculations should exemplify a typical mining operation. However, solutions from the resulting calculations may differ from actual mining operations due to differing production rates.

The time to move the chamber is variable depending upon the conditions of the mine. Generally, once installed, the chamber will be moved approximately 1000 feet for each move (based upon the WV regulations). For this analysis, a move every 6 days (5 times per month), as calculated in Appendix A, was selected. The number of personnel required to move the chamber is estimated at three persons consisting of a mechanic, electrician, and laborer. In order to eliminate any interference of coal production, these personnel will be extra personnel assigned to

the task of moving the refuge chamber – not personnel from the working section. The time required for a move is estimated at 4 hours. Any equipment or material required for the move is assumed to be already at the mine site. Therefore, the cost of any equipment or material used in the chamber move are considered incidental to the mining operations. Miscellaneous supplies required for the move are estimated at $100.00 per move.

Results

The previously defined assumptions are used to calculate annual costs for each year over the 10 year life. The annual costs are totaled, and then using common net present value calculations the present worth cost of a refuge chamber over its 10 year life is determined. The results are segmented into the previously defined sections: purchase installation and training, maintenance and inspection, and move. The summarized results are shown in Table 3.

Table 3. Present worth cost of a refuge chamber over its 10 year life.

	Present Worth Cost	Percent of Total Cost
Purchase cost	$80,000	23.4%
Installation	$700	0.2%
Training	$65,500	19.0%
Maintenance & Inspection cost	$25,400	7.4%
Moving costs	$169,600	50.0%
Total	**$341,200**	

The present worth cost to a mining company is approximately $341,200 per refuge chamber. Approximately half the cost associated with the chamber is related to the requirement for moving the chamber. The purchase cost is the next costly item, comprising 23.4% of the total present cost, with training cost following at 19%. Maintenance and inspection costs comprise only 7.4% of the total present cost. Table 4 shows the work sheet used to calculate the present worth costs of the portable refuge chamber.

The analysis uses a discount rate of 9.5%, which is approximately the current lending rate of LIBOR + 5% for a fixed rate loan (World Bank, 2007) (Bankrate.com, 2007). Determining the appropriate discount rate is an important step in conducting the cost analysis. There are many views for selecting the discount rate. However, to simplify the selection of the discount rate, the discount rate used in this analysis is based upon the cost of capital – the actual cost of financing money, rather than attempting to incorporate opportunity cost, cost of risk, and inflationary cost into the discount rate (Stermole, 2000) (Gentry, 1984). A sensitivity analysis of the discount rate is shown in Table 5, and shows the effects of varying the interest rate, i.e., if the cost of financing changes, or if the effects of the other considerations in selecting the discount rate are established.

Table 4. Present worth cost analysis worksheet for a portable refuge chamber.

Cost Analysis Sheet for Portable Refuge Chamber

			Discount rate used	9.5000%								
	Years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chamber	**Purchase & Training Costs**											
	Refuge Chamber	$80,000.00										
	Installation	$700.24										
	Training	$1,000.00										
	Personnel costs	$1,341.12	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40
	Total	**$83,041.36**	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40	$10,058.40
			PWC 10yrs.	$146,196.02								

	Years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chamber	**Maintenance costs**											
	Personnel costs											
	Manufacturer Inspection		$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
	Mine personnel Insp.		$139.74	$139.74	$139.74	$139.74	$139.74	$139.74	$139.74	$139.74	$139.74	$139.74
	Supplies											
	Batteries						$2,500.00					
	CO2 Scrubber System						$11,500.00					
	First Aid Kit						$1,000.00					
	Food & Water	$1,400.00					$1,400.00					
	Gas Monitors											
	Oxygen						$2,500.00					
	Miscellaneous											
	Total	$1,400.00	$2,139.74	$2,139.74	$2,139.74	$2,139.74	$21,039.74	$2,139.74	$2,139.74	$2,139.74	$2,139.74	$2,139.74
			PWC 10yrs.	$25,440.80								

	Years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chamber	**move costs**											
	Personnel costs		$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20	$21,007.20
	Supplies		$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
	Total	**$0.00**	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20	$27,007.20
			PWC 10yrs.	$169,572.75								
	Total Present Worth Costs			**$341,209.57**								

Table 5. Sensitivity of discount rate on present worth cost of a refuge chamber over its 10 year life.

	5% Discount Rate	9.5% Discount Rate	15% Discount Rate	20% Discount Rate
Purchase cost	$80,000	$80,000	$80,000	$80,000
Installation	$700	$700	$700	$700
Training	$80,000	$65,500	$52,800	$44,500
Maintenance & Inspection cost	$31,400	$25,400	$20,200	$16,600
Moving costs	$208,500	$169,600	$135,500	$113,200
Total	**$400,600**	**$341,200**	**$289,200**	**$255,000**

Earlier it was stated that the purchase price of a portable refuge chamber varied from $45,000 to $140,000 due to the many models available. Table 6 shows the effect of changes in purchase price on the present worth cost at the 9.5% discount rate.

Table 6. Sensitivity of purchase price on present worth cost of a refuge chamber over its 10 year life.

	$45,000 Cost	$80,000 Cost	$140,000 Cost
Purchase cost	$45,000	$80,000	$140,000
Installation	$700	$700	$700
Training	$65,500	$65,500	$65,500
Maintenance & Inspection cost	$25,400	$25,400	$25,400
Moving costs	$169,600	$169,600	$169,600
Total	**$306,200**	**$341,200**	**$401,200**

The estimates for safety training for the portable refuge chambers are expected to be accurate. However, there could be some variability in the estimates of this training. Training costs could be lower if all that is required is the initial safety training when the chamber is installed and the training necessary when the chamber is moved is incidental to any existing safety meetings currently held at the mine site. On the opposite end of the spectrum, the safety training required could be more expensive, requiring more time than was originally estimated. Table 7 shows the sensitivity analysis at the 9.5% discount rate, when the training cost is lower (i.e., chamber move training is incidental to existing training) and when the time required for safety training after each move is doubled.

Table 7. Sensitivity of safety training costs on present worth cost of a refuge chamber over its 10 year life.

	Lower Training Cost	Current Assumption Cost	Higher Training Cost
Purchase cost	$80,000	$80,000	$80,000
	$700	$700	$700
Training	$2,350	$65,500	$130,000
Maintenance & Inspection cost	$25,400	$25,400	$25,400
Moving costs	$169,600	$169,600	$169,600
Total	**$278,050**	**$341,200**	**$405,700**

Maintenance and inspections will not have a major impact as they make up only a small portion of the refuge chamber costs. Table 8 shows the effects of possible changes in costs for maintenance and inspections, using the 9.5% discount rate. For the lower maintenance and inspection costs, the cost of the monthly inspection performed by the mine foremen was changed to be incidental to the mine operation, rather than the original assumption of costing 15 minutes of the mine foreman's time. Additionally, the manufacturer cost for inspection was reduced to $750 per day. Cost of supplies remained the same. To calculate the higher maintenance and inspection cost. The mine foreman's time was increased to 30 minutes for the monthly inspections and the manufacturer's cost was increased to $2,000 per day. Again, cost of supplies remained the same.

Table 8. Sensitivity of maintenance and inspection costs on present worth cost of a refuge chamber over its 10 year life.

	Lower Maintenance & Inspection Cost	Current Assumption Cost	Higher Maintenance & Inspection Cost
Purchase cost	$80,000	$80,000	$80,000
Installation	$700	$700	$700
Training	$65,500	$65,500	$65,500
Maintenance & Inspection cost	$21,400	$25,400	$38,900
Moving costs	$169,600	$169,600	$169,600
Total	**$337,200**	**$341,200**	**$354,700**

Since refuge chamber move costs are a major portion of the present worth costs, any change may have a significant impact on these costs. The current assumption is that the refuge chamber is moved 60 times per year (5 times per month). A sensitivity analysis, using the 9.5% discount rate, is shown in Table 9, changing the number of required moves per year to 30 moves for the lower move alternative. The number of moves is increased to 90 moves for the higher move cost alternative. The number of hours and personnel required to move the chamber seem reasonable, and therefore, are not varied.

Table 9. Sensitivity of moving costs on present worth cost of a refuge chamber over its 10 year life.

	Lower Moving Cost	Current Assumption Cost	Higher Moving
Purchase cost	$80,000	$80,000	$80,000
Installation	$700	$700	$700
Training	$65,500	$65,500	$65,500
Maintenance & Inspection cost	$25,400	$25,400	$25,400
Moving costs	$84,800	$169,600	$254,400
Total	**$256,400**	**$341,200**	**$426,000**

Figure 2 shows a graphical summary of all the sensitivity analysis that was completed in this evaluation. In reviewing the sensitivity analysis, changes in the moving requirements of the refuge chamber have the largest impact on its cost, while changes in the inspection and maintenance had the smallest impact. Training costs also had a significant impact and could be much larger as this analysis only examined the cost of training the personnel on the working section – not the cost of training all mine personnel. Purchase price also impacts the costs significantly, especially as the purchase price becomes higher. Changing the discount rate also would have an impact on the costs. However, selecting the best discount rate to use for this cost analysis is dependent upon the individual mining companies, and is best left to their discretion.

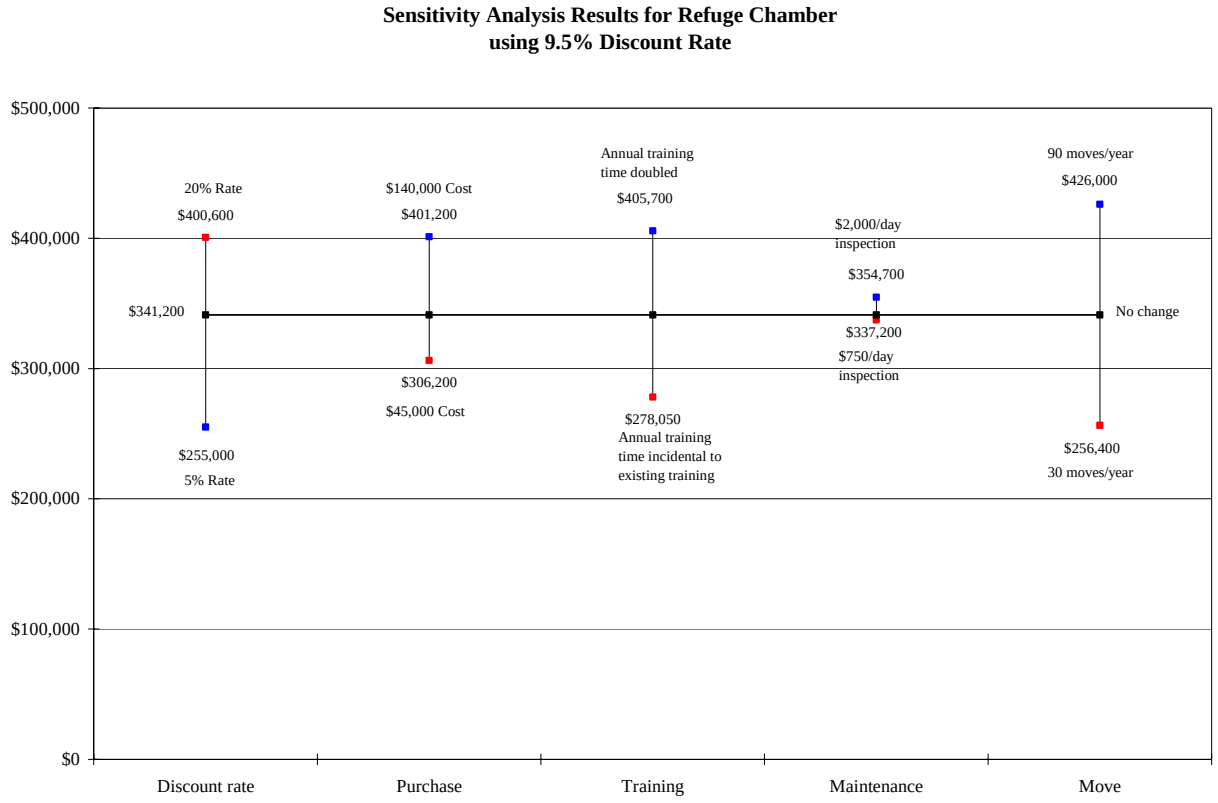

Figure 2. Summary of sensitivity analysis completed on refuge chamber costs.

Table 10 shows the results of the sensitivity analysis if all the lower alternatives (except for discount rate) occurring for each segment, purchase, training, maintenance, and move, are combined. It also shows the combination of all the higher alternatives for each segment. While the possibility of each of the lower alternatives occurring simultaneously at a mine site is low, the result of this combination is shown because of the variable nature of mining conditions at each mine site. This results in a possible total low refuge chamber cost of $154,250. The combination of all the higher alternatives occurring simultaneously is more probable and results in a possible high refuge chamber cost of $564,000. These lower and higher costs show the effects (optimal for lower cost alternatives and worst case for higher cost alternatives) of changes to the current single refuge chamber cost of $341,200 as calculated in this analysis.

Table 10. Combined Sensitivity Analysis Results

	Low	High
Purchase	$45,000	$140,000
Installation	$700	$700
Training	$2,350	$130,000
Maintenance	$21,400	$38,900
Move	$84,800	$254,400
Total	**$154,250**	**$564,000**

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Appendix A. Amount of time available between required refuge chamber moves.

3 Entry system (room and pillar)

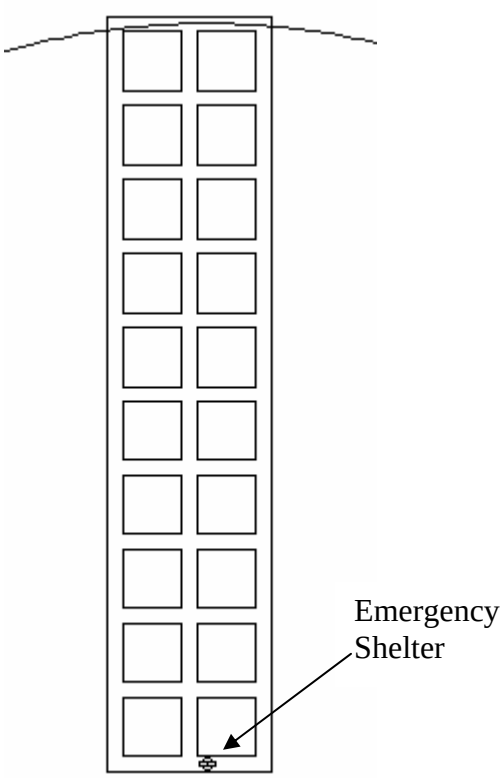

Figure A1. Area available for mining for 3 entry system: Arc is limit for 1000 ft distance away from face assuming linear advance.

Assumptions:

Production occurs 24 hours/day 365 days/year.
100 ft. centers – pillars

Production rate[3]	1,400 tons/shift
Availability	85%
Entry width	20 ft.
Seam height	6 ft.
Coal density[4]	82.4 lb/ft^3

Volume of coal mined between pillars

V_{mp} = [(20+40+100+40+20)x20x6]+[20x40x6x6]
V_{mp} = 55,200 ft^3

[3] Whipkey, K., "Productivity Improvement for Longwall Development." Coal Age, (August 2005) 28-32.
[4] Kentucky Geological Survey, "Estimating Tons of Coal on a Property." Website: www.uky.edu/KGS/coal/estimatingTons.htm, last accessed November 2007.

Volume at start of 1000' advance

V_{s1000} = [(20+40+100+40+20)x20x6]+[20x40x6x3]

V_{s1000} = 40,800 ft^3

Total volume mined before move

$V_{tot} = V_{mp}\ V_{s1000}$

V_{tot} = (55,200 ft^3 x 9)+ 40,800 ft^3

V_{tot} = 537,600 ft^3

Total tons mined before move

Tons = (537,600 ft^3 x 82.4 lb/ft^3) 2,000lb

Tons = 22,149

Tons mined per day for continous miner

Tons/day = (1,400 tons/day x 3 shifts/day x 0.85)

Tons/day = 3570

Number of days of mining before move

Days = (22,149 tons)/ 3570 tons/day

Days = 6.2 days

Days = 6

Therefore, move chamber every 6 days.

9 Entry system (room and pillar)

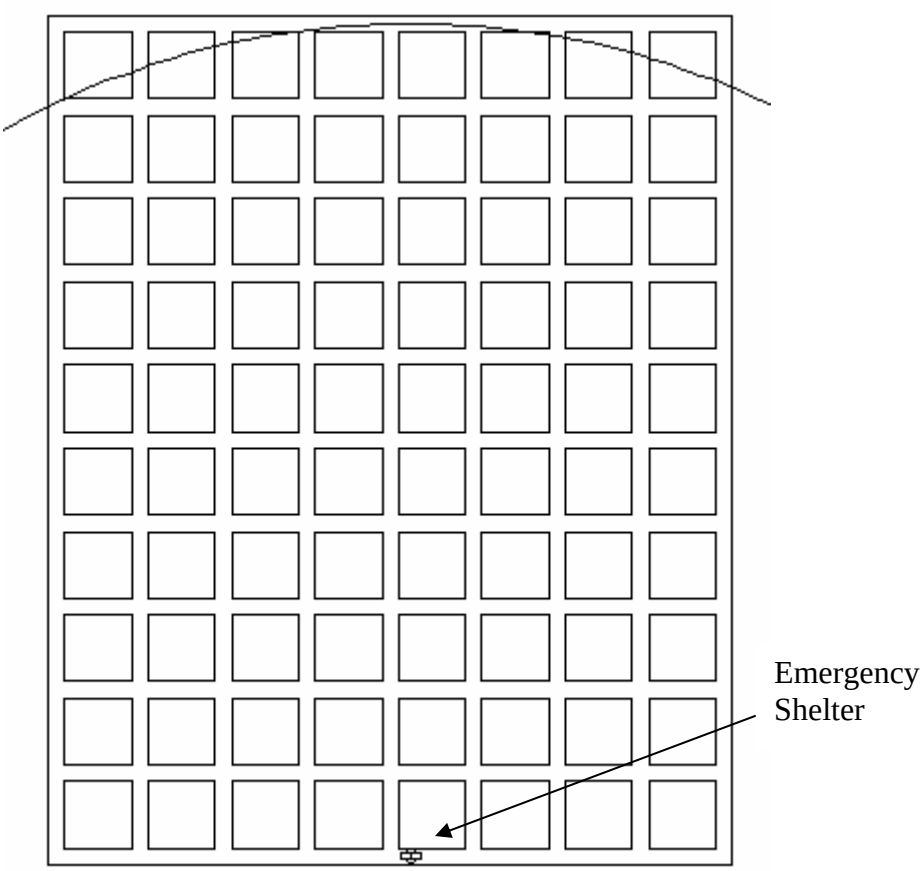

Figure A2. Area available for mining for 9 entry system: Arc is limit for 1000 ft distance away from face assuming linear advance.

Assumptions:

Production occurs 24 hours/day 365 days/year.
100 ft. centers – pillars

Production rate	1,400 tons/shift
Availability	85%
Entry width	20 ft.
Seam height	6 ft.
Coal density	82.4 lb/ft^3

Volume of coal mined between pillars

V_{mp} = [(20+40+700+40+20)x20x6]+[20x40x6x18]

V_{mp} = 184,400 ft^3

Volume at start of 1000’ advance

V_{s1000} = [(20+40+700+40+20)x20x6]+[20x40x6x9]

V_{s1000} = 141,600 ft^3

Total volume mined before move

$V_{tot} = V_{mp}\ V_{s1000}$

V_{tot} = (184,800 ft^3 x 9)+ 141,600 ft^3

V_{tot} = 1,677,800 ft^3

Total tons mined before move

Tons = (1,677,800 ft^3 x 82.4 lb/ft^3) 2,000lb

Tons = 69,125

Tons mined per day for continous miner

Tons/day = (1,400 tons/day x 3 shifts/day x 0.85)

Tons/day = 3570

Number of days of mining before move

Days = (69,125 tons)/ 3570 tons/day

Days = 19.36 days

Days = 19

However, 9 entry systems are generally super-sections with 2 continuous miners. Therefore production doubles, reducing the number of days before move by half.

Days = 19/2

Days = 9.5

Days = 9

Therefore, move chamber every 9 days.

Longwall system

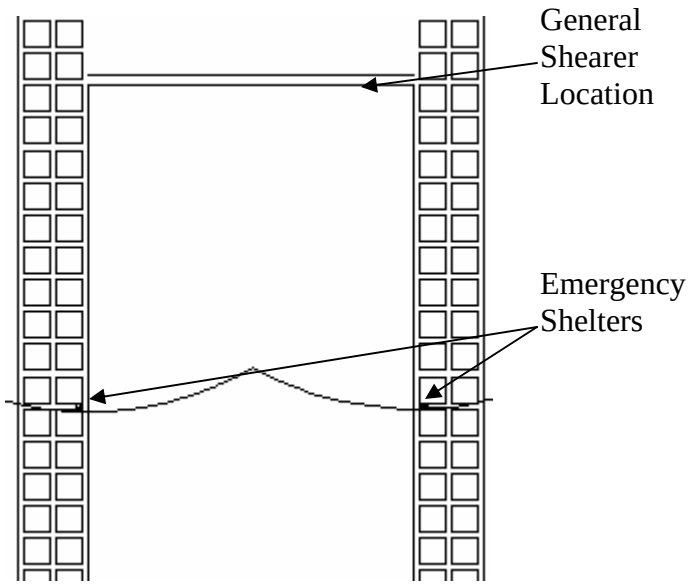

Figure A3. Area available for mining for longwall system: Arcs are limits for 1000 ft distance away from face assuming linear advance.

Assumptions:

Production occurs 24 hours/day 365 days/year.

Production[5]	7.5 million tons/year
Panel[6]	1450 ft.
Seam height[7]	7 ft.
Coal density	82.4 lb/ft^3

Tons mined per day for longwall

Tons/day = (7,500,000 tons /365 days)
Tons/day = 20,550

Volume mined per day

V_m = (20,550 tons x 2000 lb/tons)/ 82.4 lb/ft^3
V_m = 498,786 ft^3

Rate of advance per day

Rate = (498786 ft^3)/(7 ft x 1450 ft)
Rate = 49 ft

[5] Fiscor, S., "U.S. Longwall Census." Coal Age, (February 2007) 30-38.
[6] Ibid.
[7] Ibid.

Number of days of mining before move

Days = 1000 ft / 50 ft
Days = 20.5 days
Days = 20

Therefore, move chamber ahead of longwall every 20 days.