Results of noise measurements from underground testing of a roof bolting machine duty cycle

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1. ABSTRACT

Data collected by the Mine Safety and Health Administration (MSHA) has shown that roof bolting machine (RBM) operators are the second most likely type of underground mining machine operator to be are over exposed to noise, per the MSHA Permissible Exposure Limit. In response to this, the Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) has initiated a project to develop engineering noise controls for roof bolting machines. Key to this research is an evaluation of the duty cycle of a typical roof bolting machine operation and this paper presents the results of such an exercise for data collected at two cooperating coalmines. The evaluation entails a time motion study of an operators' shift, logging each activity for time (e.g., tramming the machine, drilling holes, installing the roof bolt, etc.) and the noise levels associated with each task with a Larson Davis Spark 705+ dosimeter. NIOSH post processed the data to determine which tasks the operator devotes the most time to and the noise dosage accumulated during those tasks. These results provide insight into which portion of the operators' duty cycle is the most prominent contributor to noise exposure and thus, where research activities for the development of engineering noise controls should be focused. It was determined that the task of drilling holes is the most significant source of the operators' noise exposure and project research has focused on engineering noise controls to reduce the noise emissions generated during the drilling portion of the machine duty cycle.

2. INTRODUCTION

NIOSH's National Occupational Research Agenda lists hearing loss among its 21 Priority Research Areas and its Pittsburgh Research Laboratory maintains a Hearing Loss Prevention Branch to investigate reducing Noise Induced Hearing Loss (NIHL). MSHA coal noise sample

data collected from 2000 to 2005 show that only seven types of machines compose the bulk of the equipment whose operators exceed 100% noise dosage, per the MSHA Permissible Exposure Level (PEL). Of these machines, the roof bolting machine operator was the second most likely to be over exposed among operators of all equipment used in underground coal.[2]

Underground coal mining requires a roof control plan to ensure the safety of its workforce. After the removal of coal or rock, the remaining strata may be subject to fall, either from overhead or from the side. One method used in underground coalmines to prevent roof failures requires the installation of roof bolts, of sometimes-varying lengths, at roughly 1.2 m (four-foot) intervals. A RBM installs roof bolts by tramming to the required location, drilling a hole, and then installing the bolt.

Commonly used roof bolts employ either mechanical anchors, resin, rebar, or a combination of both to secure the bolt. There are other types of roof bolts available as well. Examples of resin rebar roof bolts are shown in Figure 1. Drill steels are either round or hexagonal in shape and are available to mate with either 2.54 cm (one inch) or 3.49 cm (1 3/8 inch) drill bits (Figure 2). Drill bits are available for vacuum drilling i.e., dry, and for mist or wet drilling (Figure 3). The operator installs a bit on a drill steel, places the drill steel in the RBM chuck and then drills the hole for the roof bolt. The operator removes the drill steel from the chuck, replaces it with a wrench holding the roof bolt, inserts the resin into the hole, if used, drives the roof bolt into the hole with the RBM, then rotates the bolt for a predetermined length of time and thrust until the resin sets. The operator repeats this exercise as needed to meet the requirements of the mines roof control plan.

Figure 1: Resin bar roof bolts

Figure 2: Drill steels, hex (top), round (bottom)

Figure 3: Drill bits, vacuum (top), wet or mist (bottom)

Essential to developing engineering noise controls to reduce the occurrences of NIHL for roof bolting machine operators, was to document the noise doses and sound levels associated with the typical tasks required of a RBM operator, and the time spent conducting these tasks. A time motion study of an operators shift comprised logging each activity for the time spent conducting a particular activity (e.g., tramming the machine, drilling holes, installing the roof bolt, etc.) and the noise levels associated with these tasks. Post-processing of this data reveals the tasks the operator devotes the most time to, the noise dosage accumulated during each task and of course then, the tasks which are the primarily contributors to the operators' noise dose exposure. This

information would then guide NIOSH in determining which areas of the RBM should be addressed when developing engineering controls to reduce noise emissions.

Over the course of three days, project personnel conducted three time-motion studies at cooperating coalmines and documented the noise dose exposures and activities of four RBM operators and two operators of a bolter-miner, a machine that serves as a RBM and a continuous mining machine in combination. Results of these studies confirmed our initial expectation that for the RBM, the drilling portion of the operators' duty cycle exposed the operator to the highest noise levels and was a significant contributor to the operators' noise dose, relative to other tasks.

3. TIME-MOTION STUDY 1

NIOSH personnel conducted a dosimeter time-motion study of dual-boom Fletcher roof bolting machines at two portals, A & B, of an underground coalmine. A Larson Davis Spark 705+ can set used as four separate dosimeters, each configured differently. Table 1 lists the configuration settings for this time study. Dosimeter 1 was set up to collect data per the MSHA PEL and dosimeter 4 for all noise, or wide range. Table 2 lists the noise dose accumulation and equivalent time weighted average sound pressure levels for the four RBM operators. At each portal, the RBM's were configured for vacuum drilling and 2.54 cm (one inch) bits.

Table 1 – Larson Davis Spark 705+ dosimeter settings

Dosimeter	Threshold level (dB)	Exchange rate (dB)	Criterion level (dB)	Weighting	Response
1 – MSHA PEL	90	5	90	A	slow
2	85	5	90		
3	85	3	90		
4 - wide-range	40	3	85		

Table 2 – Operator noise dose and equivalent time weighted average

	Portal A - Operator		Portal B - Operator	
	A1	A2	B1	B2
Noise dose (%)	78	127	43	65
Noise dose, 8 hrs (%)	52	85	29	43
TWA (dB)	85	89	81	84
TWA, 8 hrs (dB)	88	92	84	87

Both operators for each machine were observed during shift exercises and the tasks were manually logged on a second-by-second basis. Primary tasks logged include; the drilling of the bolt hole, installing the bolt; tramming of the RBM; riding the man-trip to the section; prep time; and riding the elevator down the shaft. For each of these tasks, accumulated times and their associated noise dosages were compiled. Shown in Figures 4-7 are the noise accumulations over

time and in Figures 8 and 9 are the tasks for which the operator was engaged at least 1% of his shift. Included in the 'other' category of Figures 8 and 9 includes time spent riding the elevator, when the operators were bolting alone, or both drilling, or both bolting, and other times where the activity could not be documented. At portal B, there was an equipment malfunction near midday and the section to shut down for the day. The effects of these 'other' conditions on the noise dose are minimal, as 93% of the operator noise dose exposures for portals A & B are attributable to those activities shown in Figures 8 and 9.

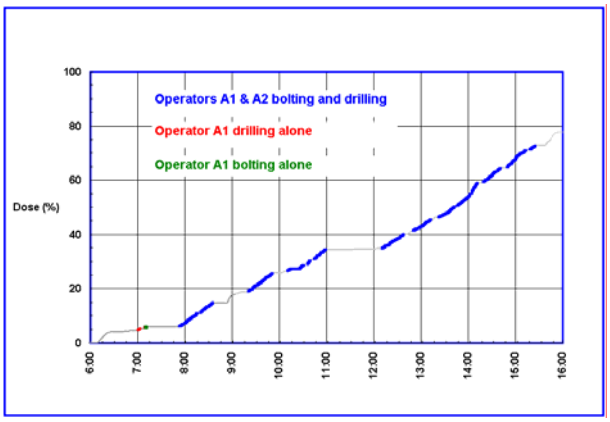

Figure 4: Noise dose accumulation, operator A1, portal A

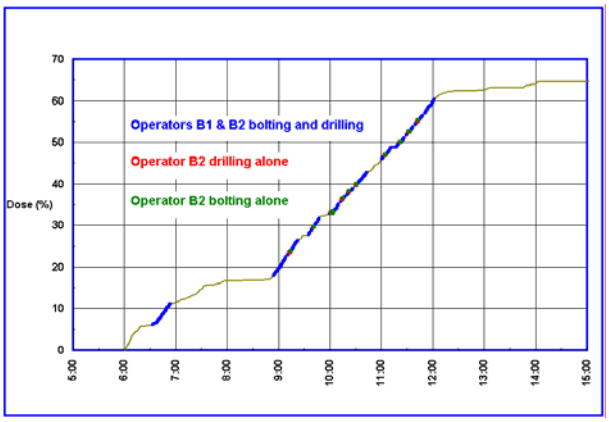

Figure 7: Noise dose accumulation, operator B2, portal B

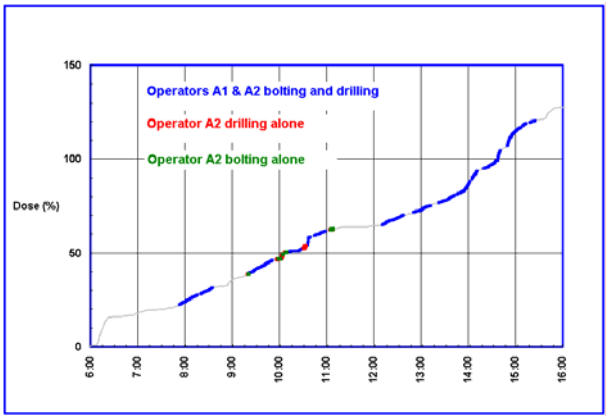

Figure 5: Noise dose accumulation, operator A2, portal A

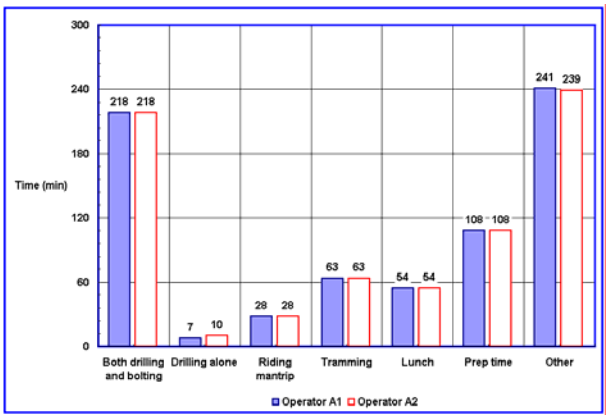

Figure 8: Time spent by task, portal A

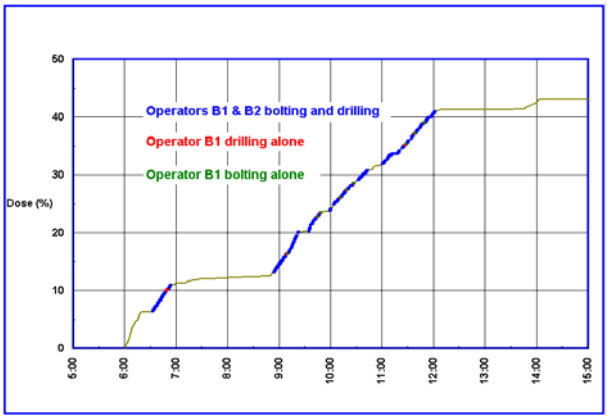

Figure 6: Noise dose accumulation, operator B1, portal B

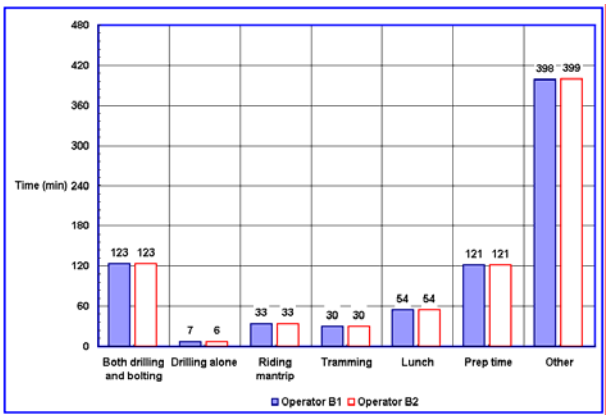

Figure 9: Time spent by task, portal B

Figures 10 and 11 show that periods of time when both operators were drilling and bolting contribute a minimum of one-half of the operators accumulated exposure while no other task contributes as much as one-fifth. Further analysis of the data indicated that the bulk of the time spent either drilling or bolting were in situations where is was difficult to discern between the operators' drilling and bolting activities (Table 3). Thus, over 90% of this data involves the operators drilling and bolting simultaneously.

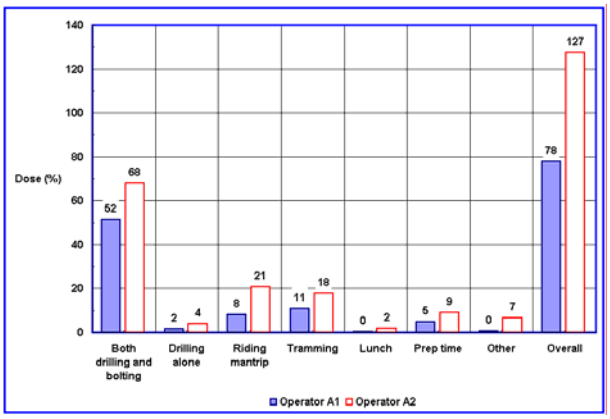

Figure 10: Dose by task, portal A

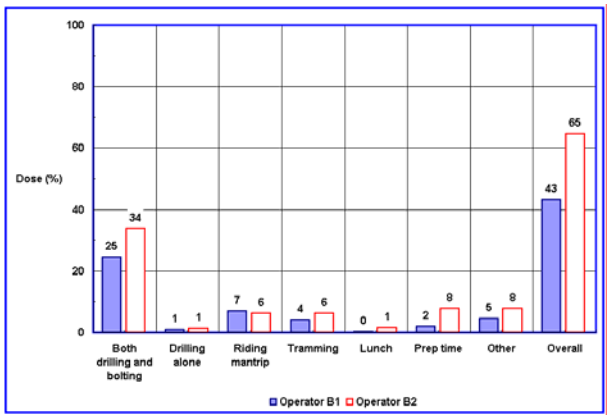

Figure 11: Dose by task, portal B

Table 3 – Percentage of time spent drilling and bolting[1]

	Portal A – Operator		Portal B – Operator	
	A1	A2	B1	B2
Drilling & bolting simultaneously	96	95	94	94
Drilling alone	3	4	5	5
Bolting alone	0[2]	0[2]	1	1
Drilling together	0[2]	0[2]	----[3]	----[3]
Bolting together	0[2]	0[2]	----[3]	----[3]

[1] – Considering only time spent drilling and/or bolting.

[2] – Less than 1%.

[3] – No observations of this activity.

However, it was necessary to determine the noise levels and exposures the operators were exposed to when drilling or bolting singly during the duty cycle. NIOSH documented multiple instances of the drilling/bolting cycle to determine the time spent drilling a hole and then to install the bolt into the associated hole. In all, 27 drilling/bolting cycles were observed and mean values for these for each of three operators are given Figure 12. Researchers were able to document multiple instances where Operator A1 drilled alone, but only one complete drilling/bolting cycle. Thus, Operator A1 data is not included in Figure 12. Clearly, drilling of the hole requires significantly more time than the associated installing of the roof bolt. This was expected, as the roof bolt resin hardens very quickly. Further, the operator is exposed to greater

sound pressures during drilling than bolting (Figure 13), and thus accumulates dose at significantly faster rate when drilling than bolting (Figure 14). From this, the operator would be expected to accumulate significantly more dose exposure during drilling than bolting.

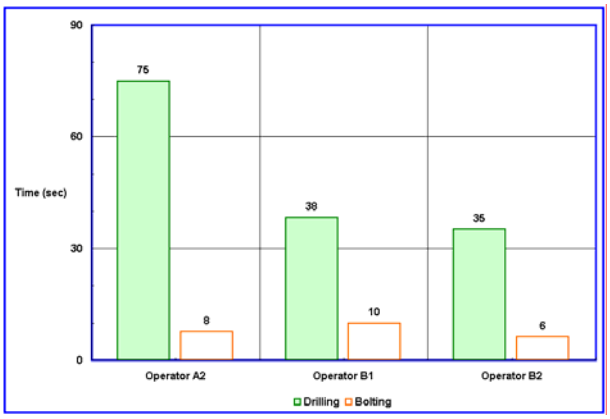

Figure 12: Mean drilling and bolting time, portals A & B

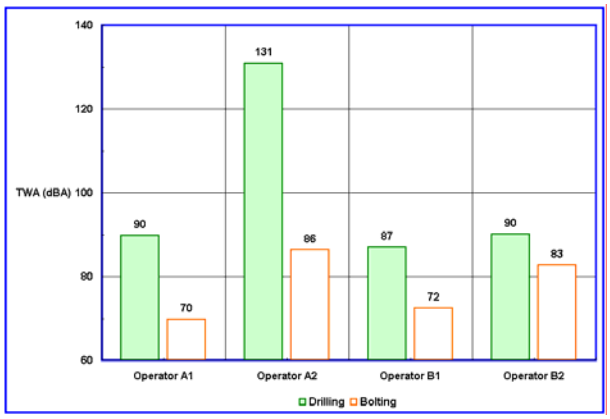

Figure 13: Equivalent time weighted average sound pressure level, portals A & B

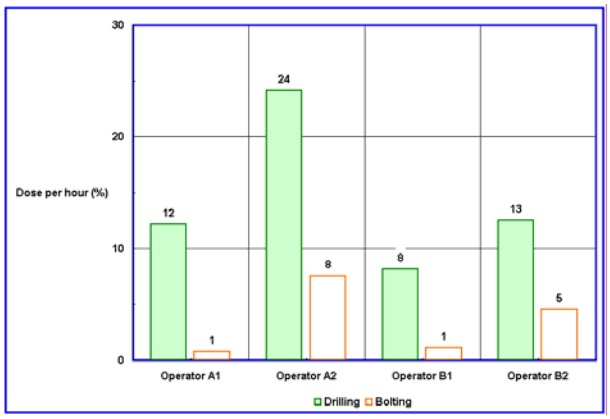

Figure 14: Mean drilling and bolting dose per hour, portals A & B

Both operators accumulated noise dose at significant rates when drilling and/or bolting, 12-24 % per hour at portal A and 8-16 % per hour at portal BA. Figures 15 and 16 show the RBM operators dose accumulation per hour by task for this time study. During the ride on the man trip from the elevator to the section and back, the operators accumulate noise exposure at a significant rate, 44% per hour for Operator A2, and 18% for Operator A1. However, for both portals, man trip time was only roughly 30 minutes (Figures 8 and 9) and its contribution to noise exposure relatively small compared to drilling and bolting (Figures 10 and 11).

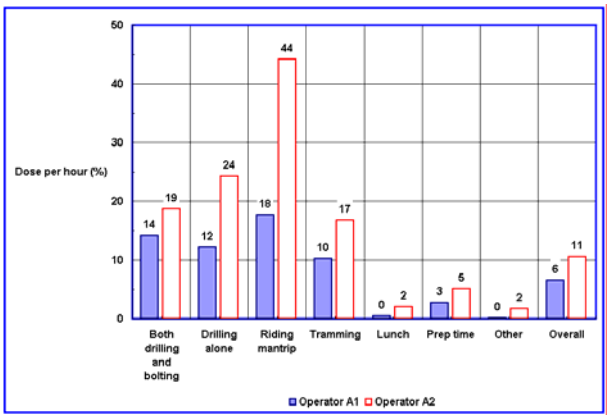

Figure 15: Dose per hour by task, portal A

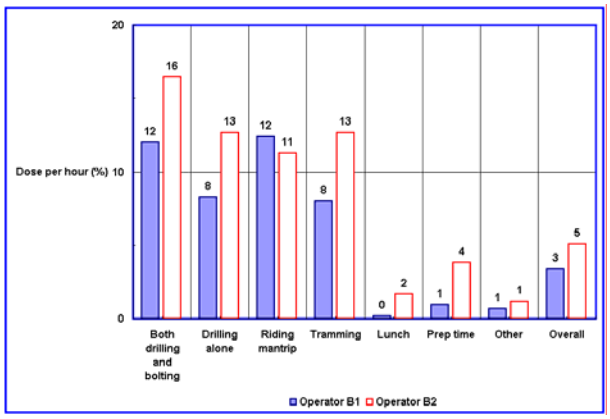

Figure 16: Dose per hour by task, portal B

These results suggest that if the noise dose exposure for an RBM operator is to be reduced, then the drilling portion of the operators' should be evaluated and engineering noise controls developed to reduce drilling noise emissions. Laboratory investigations in NIOSH's Hemi-anechoic Chamber (HAC) also support the initial premise that drilling noise should be addressed. Sound pressure level measurements made at the RBM operator ear location confirm that drilling generates higher noise levels than bolting (Table 4).

Table 4 – Operator ear sound pressure levels

Roof bolting machine condition	Level (dBA)
idling	72
+ vacuum	80 - 90
+ vacuum + bolting	92 - 95
+ vacuum + drilling	97 - 108

3. TIME-MOTION STUDY 2

NIOSH personnel conducted a dosimeter time-motion study of a dual-boom Voest-Alpine bolter-miner, type 14ABM, at a second cooperating coalmine. The Larson Davis Spark 705+ dosimeter settings shown in Table 1 were again used for this study. The bolter miner was configured for vacuum drilling and 3.49 cm (1 3/8 inch) bits. Both bolter operators for the machine (Operator C1 and Operator C2) were observed during shift exercises and again, the tasks were manually logged on a second-by-second basis. Here, in addition to the two roof bolter operators, NIOSH collected noise dose exposure data for the continuous miner operator (CM1) and the loader operator (L1), who carried coal away from the section.

Figure 17 shows the noise dose accumulation over time for these four miners and Table 5 lists the overall dose accumulation and the equivalent time weighted average sound pressure levels. The addition of the coal cutting, conveying, and loading at this location contributed greatly to the complexity of the operation. Thus, the activities of the four individuals were not documented as before, but the general activity of the section was logged. Primary tasks logged included those from portals A & B; the drilling of the bolt hole; installing the bolt; tramming of the RBM; riding

the man-trip to the section, prep time; and riding the elevator down the shaft; but also include the addition of the cutting, conveying and loading of the coal.

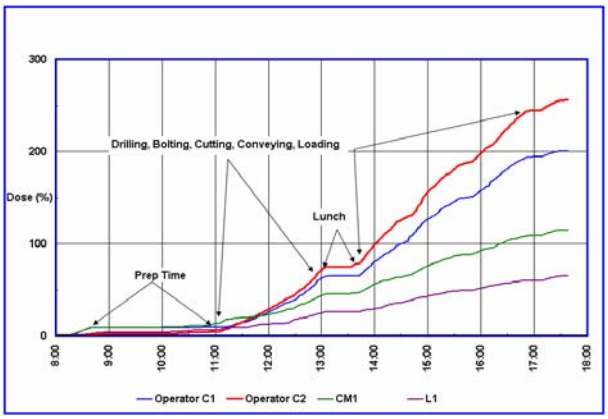

Figure 17: Noise dose accumulation, portal C

Table 5 – Operator noise dose and equivalent time weighted average sound pressure levels

	C1	C2	CM1	L1
Noise dose (%)	200	256	115	65
Noise dose, 8 hrs (%)	133	171	77	43
TWA (dB)	92	94	88	84
TWA, 8 hrs (dB)	95	97	91	87

Figure 18 illustrates the tasks representing at least 1% of the time utilized during the shift. In this case, included in the 'other' category are times spent in the elevator, for maintenance, coal conveying only, when both RBM operators were bolting, or drilling or bolting singly, and lunch. Figures 19 and 20 shows the dose accumulation for each task. Operators C1 and C2 accumulated a significant portion of their exposure during cutting and conveying as well as while coal was being loaded, as these tasks accounted for roughly 45% of their dose exposure. As expected, CM1 was exposed to the most noise during cutting and conveying and L1 during loading. During the 'other' time, the RBM operators accumulated one-fifth of their noise dose, the continuous miner operator one-seventh his dose, and the loader operator accumulated none.

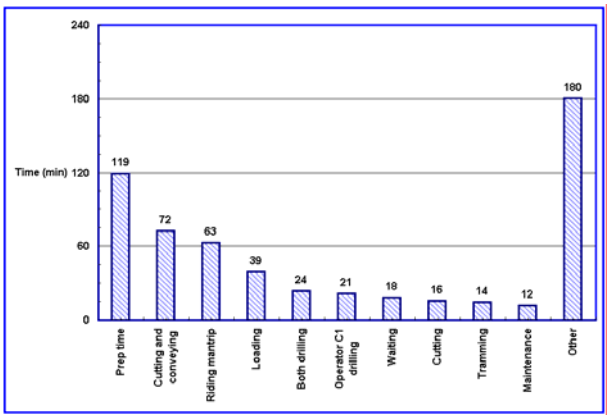

Figure 18: Time spent by task, portal C

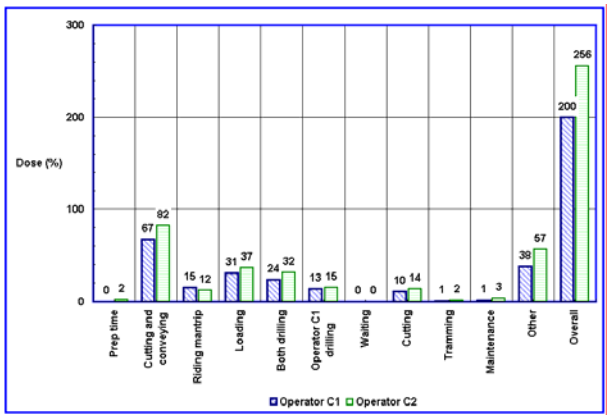

Figure 19: Dose by task, RBM operators, portal C

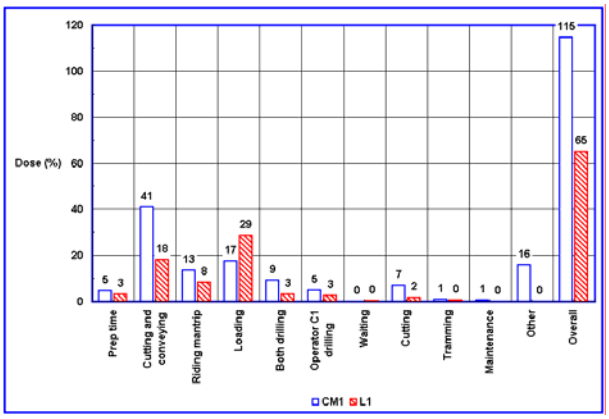

Figure 20: Dose by task, CM and loader operators, portal C

Operators C1 and C2, however, accumulated dose at significants rate while both were drilling (Figure 21), 61% dose per hour for C1 and 81% per hour for C2. They also rapidly accumulated exposure during cutting and conveying (56 and 68% per hour), loading (47 and 56% per hour) and cutting (41 & 54% per hour). It appears the roof bolting machine operators noise exposure is adversely affected by the continuous mining and loading activity in the immediate vicinity. Simultaneous cutting and conveying, cutting alone, and loading were, as expected, the tasks during which CM1 was exposed to the most noise and loading most affected L1 (Figure 22). The equivalent time weighted average for the tasks and an overall value are given in Figures 23 and 24. Many are in excess of 100 dBA, indicating that exposure to that activity for only 2 hours would exhaust the miners' permissible 100% dosage.

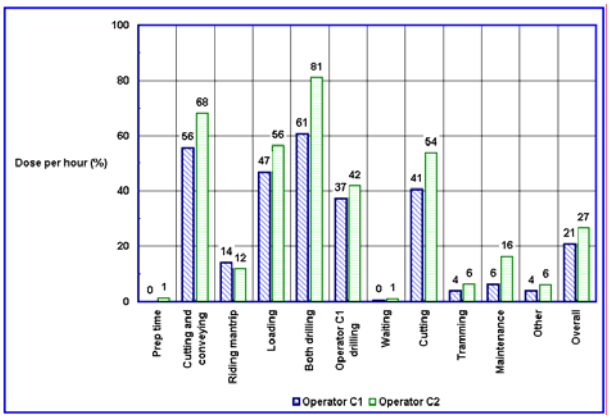

Figure 21: Dose per hour by task, RBM operators, portal C

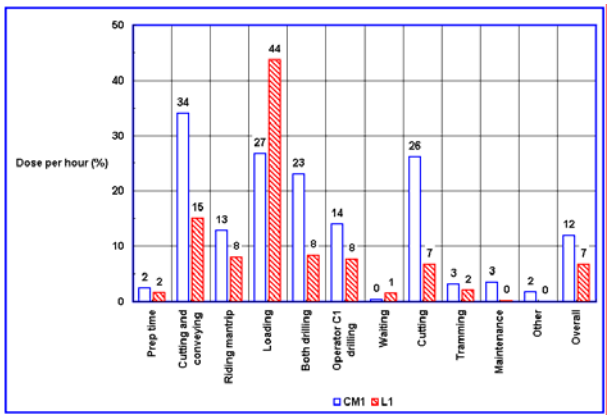

Figure 22: Dose per hour by task, CM and loader operators, portal C

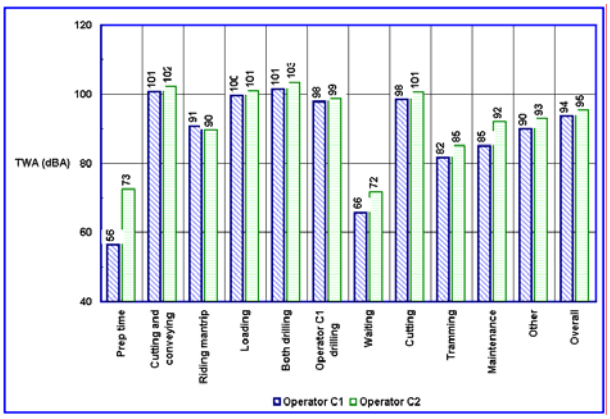

Figure 23: Equivalent time weighted average sound pressure level by task, RBM operators, portal C

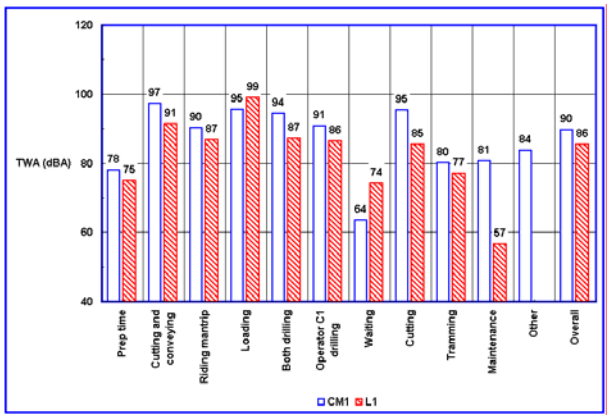

Figure 24: Equivalent time weighted average sound pressure level by task, CM and loader operators, portal C

4. CONCLUSIONS

The time-motion study conducted with the dual-boom Fletcher RBM supports NIOSH's premise that roof drilling is a significant contributor to the RBM operators' noise dose. During the time in which these operators accumulated greater than 90% of their noise exposure, a significant portion of that time was devoted to roof drilling and bolting. Additional analysis indicated that the operators spent four to nine times longer drilling than bolting during a drilling/bolting cycle and accumulated dose three to twelve times more quickly when drilling than bolting. This has narrowed the focus of the engineering noise control research to drilling noise and NIOSH is currently focusing on the drill steel, drill bit, and chuck areas of the RBM.

The second time motion study on the dual-boom Voest-Alpine miner-bolter (portal C) appears to indicate that the addition of cutting and conveying by the continuous miner and the addition of the coal loading complicated matters significantly when attempting to discern task noise dose contributions for the roof bolting machine operators. The RBM operators at portals A & B, in general, were not exposed to cutting, conveying, or loading noise. The miner bolter operators did accumulate significant noise dosages (200 and 255%) and very quickly when they were drilling simultaneously (61 and 81% per hour). Noise controls reducing drilling noise emissions should help reduce operator noise dose exposure. However, for this particular case, additional reductions in cutting and conveying noise may well be warranted if significant reductions in operator exposure are to be achieved.

REFERENCES

[1] National Institute for Occupational Safety and Health, 1996. National Occupational Agenda, DHHS Publication No. 96-115.

[2] Title 30 CFR Part 62, 2000-2005, U.S. Department of Labor, Mine Safety and Health Administration, Information Resource Center, Denver, Co.