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DEVELOPMENT OF A MANUALLY OPERATED  
RESCUE TEAM VEHICLE

Prepared for

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Bureau of Mines  
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FINAL REPORT

2 February 1978

Contract H0122063  
Development of a Manually Operated Rescue Team Vehicle

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16. Abstract (Limit: 200 words) A quick-reaction, mine permissible rescue vehicle (MERV) was developed for use by rescue teams. The MERV is a 6-wheeled, battery-powered unit with life support equipment and instrumentation; designed for a two-man team, with provisions for handling two victims or tools in a trailer. The vehicle is 100 inches long, 56 inches wide, and maximum height of 34 inches. It can be lowered down most mine shafts and has clearance to travel mine railways. The vehicle has power to all six wheels with power transmitted separately to either or both sets of wheels. Low-pressure, high-traction tires give the vehicle the ability to handle soft, muddy mine floors, flooded areas and significant obstacles, and can negotiate a 45% grade. Power and life support are sufficient for a 4-hour mission. The life support system is a commercially-available, approved unit currently used by MESA rescue personnel. A payout wire system provides communication between the vehicle and home base over a distance of 10,000 feet. On-board monitoring of carbon monoxide, methane and oxygen is provided, with master and individual alarms to warn of gas concentrations outside pre-set limits. A lightweight, water-tight trailer was developed for carrying victims or hauling tools and equipment.		14.	
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## FOREWORD

This report was prepared by Mine Safety Appliances Company, Research and Engineering Division, 100 N. Braddock Avenue, Pittsburgh, Pennsylvania, under USBM Contract No. H0122063. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. George Conroy acting as the technical project officer. Ms. Gladys Varrera was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period of June 28, 1972, to January 15, 1978. The report was submitted on February 2, 1978.

The report details significant contributions from ATV Manufacturing Company, 55th Street and A.V.R.R., Pittsburgh, Pennsylvania and Delco Electronics, 6767 Hallister Avenue, Goleta, California, both major subcontractors on the project.

## 1. INTRODUCTION

The purpose of this report is to describe the work accomplished by Mine Safety Appliances Company under Contract No. H0122063. This contract required the design, development, fabrication and demonstration of a lightweight, permissible, battery-powered mine exploration and rescue vehicle (MERV-1), and the fabrication of a second unit (MERV-2).

The program was conducted in three phases: design, fabrication and demonstration. The design phase was a coordinated effort between MSA, ATV Manufacturing Company and Delco Electronics, with assistance from the several component suppliers in special areas. MSA Research and Engineering had the overall responsibility for the program and, along with ATV, developed the design of the basic vehicle. Delco conducted mobility analyses of design configurations, as presented by MSA, to develop expected performance data for the design in question. The analyses considered such parameters as tire size and pressure, soil conditions, type of steering, etc., in the evaluation program, and provided valuable criteria for selection of the final design, as well as confirmation of the selection of components in the power system. MSA had sole responsibility for the life support, instrumentation and communication.

The fabrication and initial testing of the basic power unit and trailer were conducted at ATV, with MSA installing the power system and controller. MSA independently developed and tested the instrumentation, communications and life-support subsystems and installed them in the basic vehicle.

The demonstration test program was designed and conducted by MSA -- first at MSA's Evans City location, testing adherence to general performance specifications; and finally demonstrating the vehicle capabilities in two in-mine tests. Modifications were made to the unit as a result of the testing, and the MERV-1 was turned over to the Bureau of Mines on November 19, 1973.

MERV-1 was initially designed for an 8-hour mission. The primary power was supplied by silver-zinc batteries, the only ones commercially available at the time with power-to-weight and volume ratios to meet the vehicle weight and size restrictions. These batteries are expensive and have relatively short life cycles. In addition, approved life support apparatus was not available for the total mission. As a result, a life support system had to be developed which

required an in-mine switch to a second unit. Following an evaluation by Mine Enforcement Safety Administration (MESA) rescue personnel, the MERV-1 mission was shortened to four hours. Due primarily to the shortened mission, modifications were made which achieved additional reliability in operation while gaining a significant reduction in projected manufacturing costs. These modifications included the following:

- The use of lead-acid batteries as the main power source.
- The use of an approved, commercially available 4-hours life support unit.
- The development of a self-contained, battery-power monitoring instrumentation and communication module.

With acceptance of the basic modification for MERV-1, a second unit (MERV-2) was fabricated by MSA identical to MERV-1; and the two units were delivered to the Bureau on 10 August 1977.

This report contains a general summary of the development of the MERV units, first giving a broad overview of the units as finally delivered, and then detailing the design of the various subsystems. The discussion of each subsystem summarizes major design considerations and, where applicable, problems encountered in the development. Design drawings are presented where necessary to give a more complete explanation of the subsystem design.

The performance and recommendations are presented under separate headings.

In the course of the project, in-depth studies of specific problem areas were conducted both at MSA and by others under contract to MSA, and the conclusions summarized where applicable in the main body of the report. More detailed information on these studies are included as appendices.

## 2. GENERAL DESCRIPTION AND PURPOSE

The objective of this program was to develop a quick-reaction mine-permissible MERV for use by mine rescue teams. The vehicle was to be battery-powered; to transport two men; to provide life-support, instrumentation and tools; and to be able to traverse obstacles such as roof falls and other debris.

The Bureau gave the general requirement that the vehicle be flexible to serve the variety of situations which may be encountered. More specifically, they stated that:

- The height should be minimal so as to allow it to operate in low seams. When used in low seams, the crew members will lie on the bed of the vehicle. However, accommodations for added comfort should be made for the rescue team when operating in high seams.
- In either high or low seams, the vehicle should be able to traverse roof or rib falls, timbers, rails, etc. Ground pressure should be minimal so that it can operate through soft terrain and run over obstacles without damage. It should also be able to traverse flooded areas.
- The vehicle should be small enough to be lowered below the cage of a mine shaft elevator. All internal components, including batteries, must be secured so that the vehicle can be turned on end during this operation.
- Life support must be provided for the rescue team as well as for the possible use of accident victims. Small individual oxygen supplies must allow the men to leave the vehicle for short periods of time and provide for escape should the vehicle become inoperable.
- Two-way voice communication between the vehicle and a fresh-air base should be provided. Instrumentation should be provided to monitor the mine atmosphere.
- Visibility aids should consist of regular running lights both front and rear, as well as a high intensity search light.

- A trailer or suitable substitute should be provided to transport tools or injured personnel.

All of these specific goals have been achieved. The MERV is a 6-wheeled, battery-powered unit with self-contained life-support equipment and instrumentation. It is designed for a two-man team with provisions for handling two victims or tools in a trailer (Figure 2-1).

The MERV design has achieved a major improvement in operator comfort over the stated design requirements. Rather than positioning the two operators prone on the deck, the design allows the driver to sit upright. Even with this modification, the unit can operate routinely with 48 inches of clearance and can negotiate openings constructed to 42 inches.

The vehicle is 100 inches long, 56 inches wide, and has a maximum height of 34 inches. The gross weight is about 2100 pounds. These specifications are suitable for most mine shafts and entries. Minimum ground clearance is 6 inches, sufficient to travel mine railways without hangups.

The vehicle has power to all six wheels, with a unique dual transmission providing skid steering by transmitting power separately to either or both sets of wheels. An ability to reverse the direction of either transmission gives the vehicle the capability to turn in its own length.

Low-pressure, high-traction tires give the vehicle the ability to traverse soft, muddy mine floors, flooded areas, and significant obstacles with ease. The external plastic body is water-tight. The body design, wheel spacing, power, and vehicle center of gravity are such that the vehicle can negotiate a 12-inch diameter log (Figure 2-2) or an abrupt 45 percent grade (Figure 2-3).

The power and life support are sufficient for a 4-hour mission, defined as two hours under maximum power, including lights, and two hours under half load. The life-support system is a commercially available, approved unit currently used by MESA rescue personnel, providing both walk-around and escape capability.

A payout wire system provides communication between the vehicle and home base over a distance of 10,000 feet. An added feature is an on-board speaker system providing communication from the home base to the operators when they are off the vehicle but within speaker range.

On-board monitoring of carbon monoxide, methane and oxygen is provided, with master and individual alarms to warn

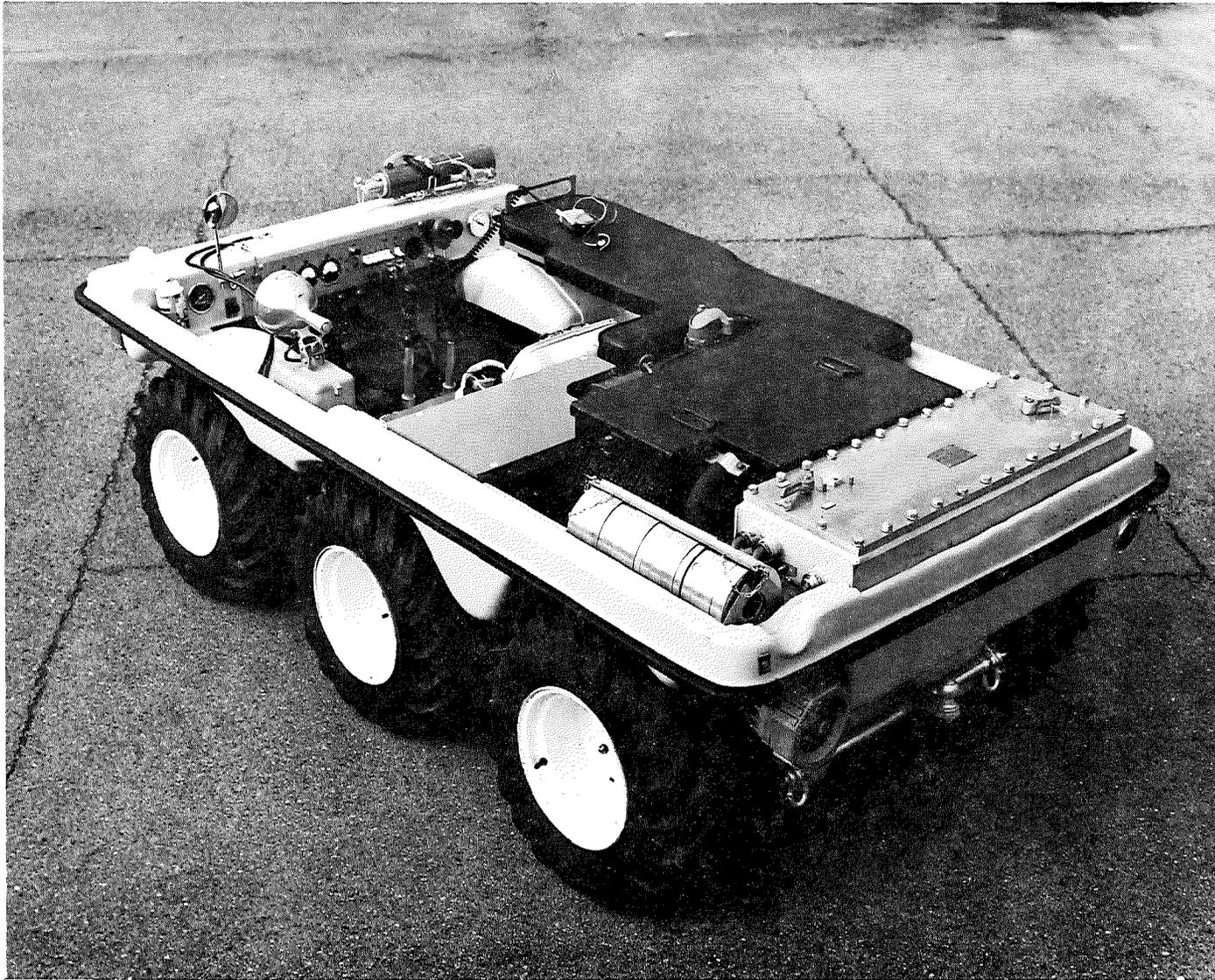


Figure 2-1 - View of MERV

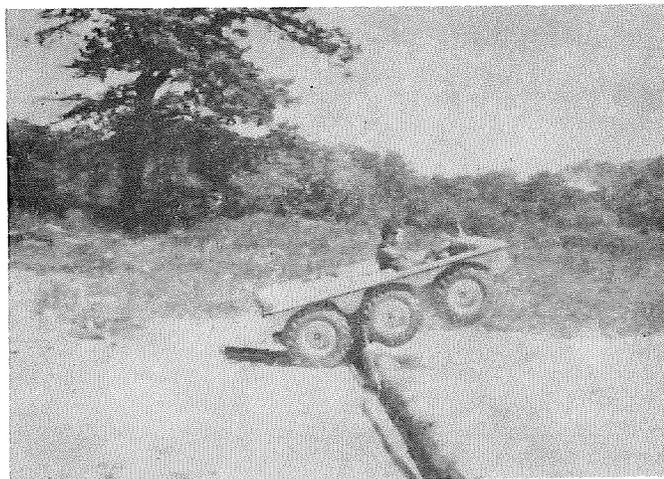


Figure 2-2 - View of the MERV  
Traversing a Log



Figure 2-3 - View of the MERV  
Climbing a 45% Grade

of gas concentrations outside of pre-set limits. Figure 2-4 shows the instrument module mounted in full view of the driver. Portable units are also provided for sampling mine atmosphere away from the vehicle.

A lightweight, water-tight trailer was developed for carrying victims or hauling tools and equipment (Figure 2-5). Low pressure tires, coupled with a suspended stretcher system, give reasonable comfort against road shocks for victims. Storage space is available for life support, equipment, tools, etc.

The MERV units meet all applicable sections of the coal mine Health and Safety Act of 1969 (P.L. 91-173) and the Bureau of Mines Schedules 2G, 9B, 10C, 13E, 14F, 19B, 21B, 23B and 29A. A formal application for certification, along with the required drawings, was made on 17 October 1973 to the Approval and Testing Office of the Pittsburgh Technical Support Center. Certification was obtained on 19 September, 1974. Extensions were granted for the modified version of the MERV, and Certification was obtained for the units as delivered per contract requirement on 24 September, 1976.

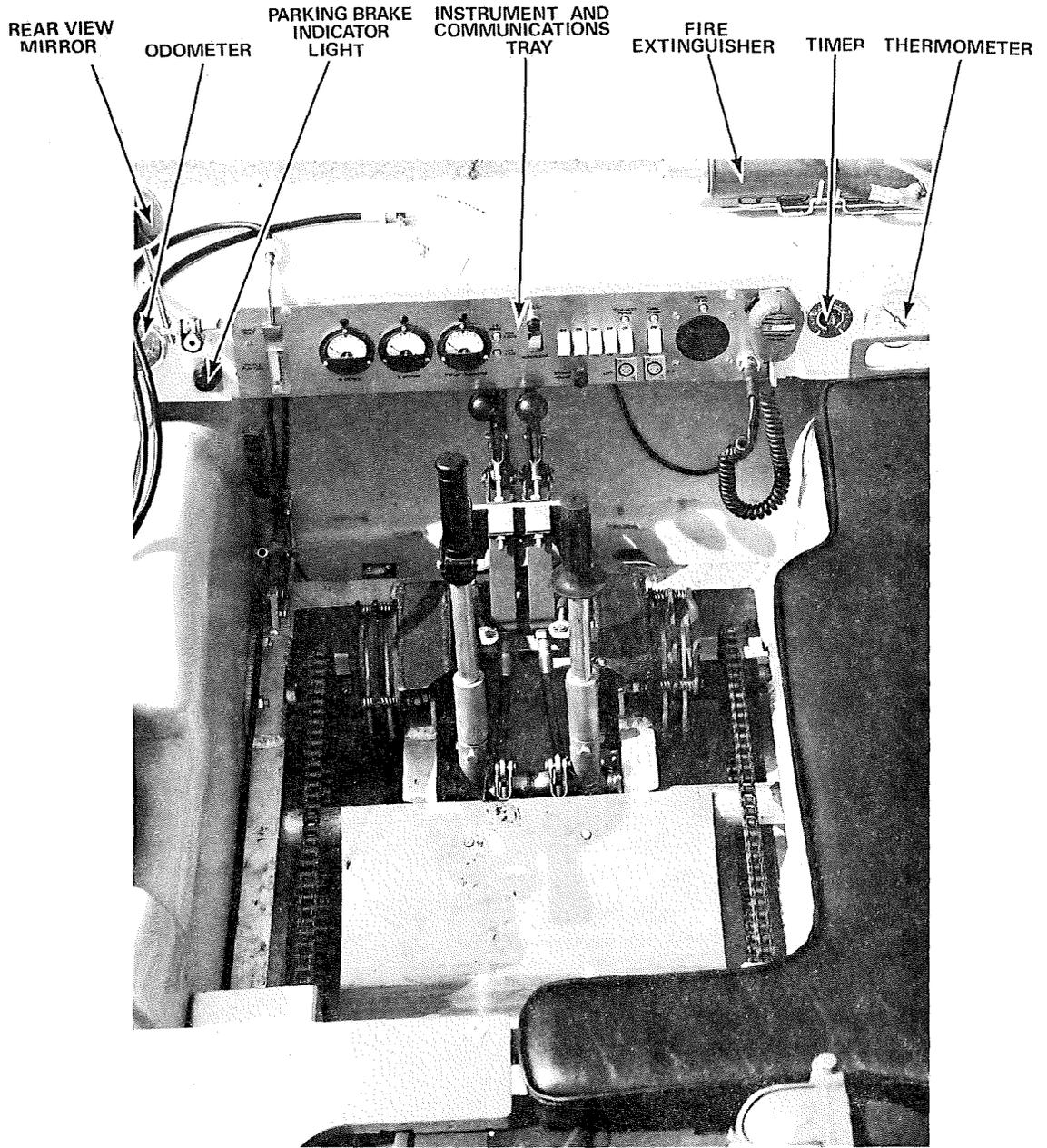


Figure 2-4 - View of Instrument Panel and Controls

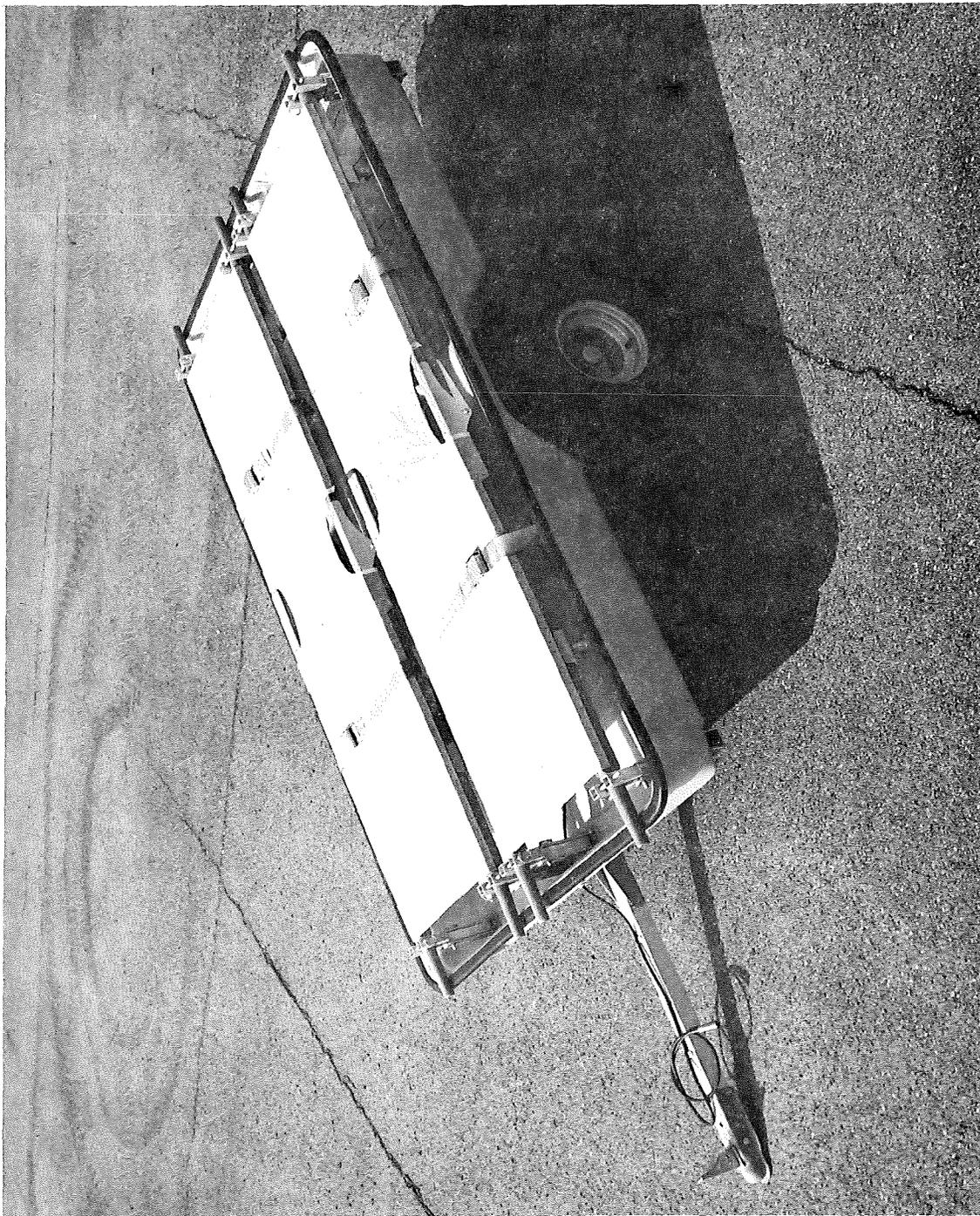


Figure 2-5 - View of Trailer

### 3. DISCUSSION

The final design of the MERV is the result of in-depth studies, testing and conferences with both Bureau and MESA mine-rescue personnel, analyzing the contract requirements in terms of the intended mission; and with ATV, Delco and component supplier personnel in deciding the best way to meet the requirements. Where possible, off-the-shelf components were utilized to keep ultimate production costs of future MERV units to a minimum.

An assembly drawing of the MERV, as delivered, is shown in Figure 3-1. The drawing shows the basic design and location of the drive-train components and vehicle accessories. The key for Figure 3-1 is given in Table 3-1.

In developing the basic concept, MSA and ATV developed several designs that would apparently fit the overall unit size and weight specifications. Variations on 6- and 8-wheeled units were considered. These were then submitted to Delco for a mobility analysis to determine which design would best meet performance specifications, with a 6-wheeled variation having the best all-around results.

Preliminary design plans were presented to the Bureau on November 6, 1972, at a scheduled Design Review meeting held at Bruceton, with both Bureau and MESA mine rescue personnel in attendance. Fabrication of the basic unit followed closely the designs presented at the meeting, with the exception of a switch in the location of the motor, controller and battery assemblies, brought on by the switch from silver-zinc to lead-acid batteries, and a change in the life-support system when the switch was made to a commercial backpack unit.

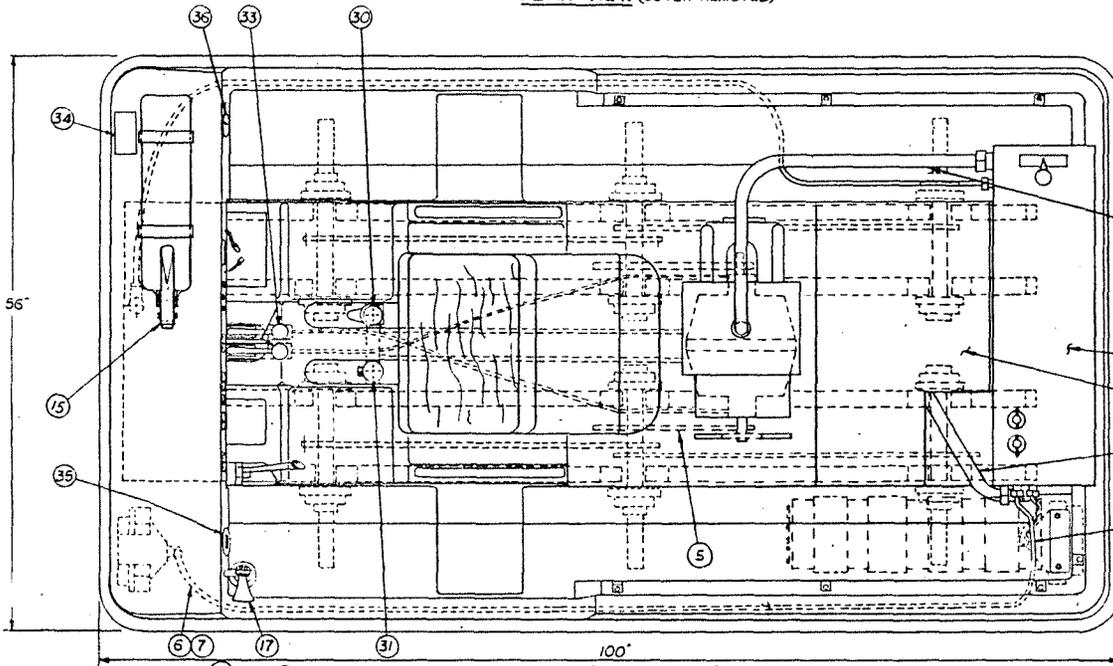
This section presents detailed discussions of each subsystem as finally fabricated and delivered to the Bureau. The philosophy behind the design of the system is presented to show the development, but discussions of problems encountered are presented only insofar as they are pertinent to the selection of the final design.

#### 3.1 BASIC VEHICLE

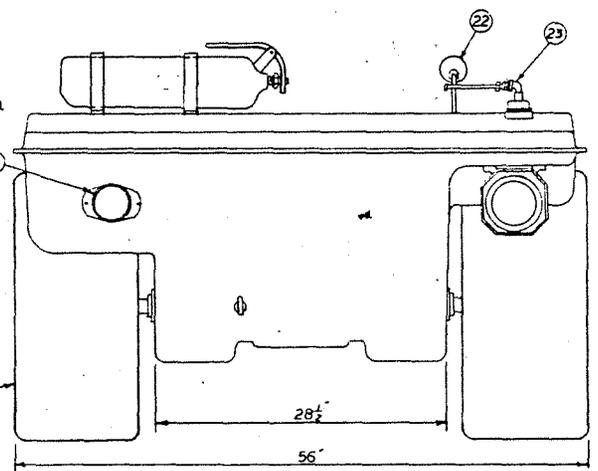
The contract Scope-of-Work for the original contract set specific design and performance parameters for the vehicle that were adhered to as strictly as possible throughout the development of the MERV. A comparison of these original specifications with the design and performance data of the MERV units is shown in Table 3-2.

PLAN VIEW (COVER REMOVED)

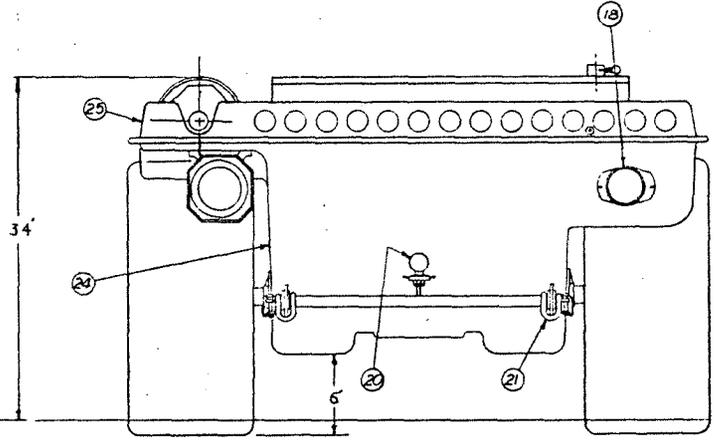
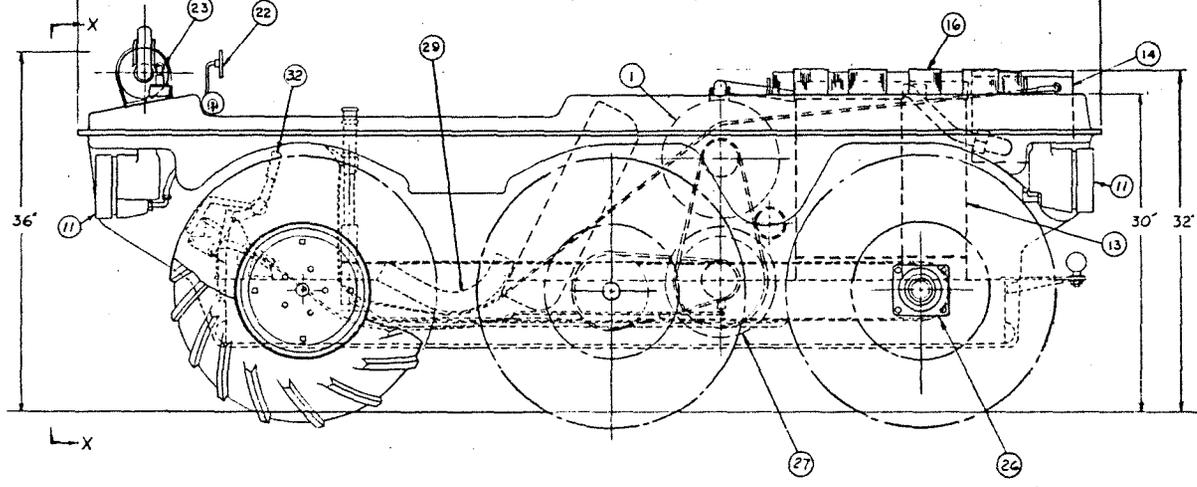
NOTES: MAXIMUM ALLOWABLE CIRCUIT BREAKER INSTANTANEOUS SETTING IS 800 AMPERES.  
 ACTUAL CIRCUIT BREAKER SETTING IS 300 AMPS.  
 SCR DRIVE OVERLOAD TRIP SETTING IS 242 AMPS.  
 FOR ELECTRICAL COMPONENTS SEE DWG. CSK 3019-182  
 FOR GENERAL WIRING DIAGRAM AND SCHEMATIC SEE DWG. A-AC-898-26



NOTE  
 MOTOR CABLE IS #4-4COND.  
 1.27" O.D. x 8 FT. L.G., FLAME  
 RESISTANT PER SCHED. 26  
 CONDUIT HOSE IS 1 1/2" I.D. x  
 1 1/8" O.D. x 8 FT. L.G., FLAME  
 RESISTANT PER MESA 50126



VIEW 'X-X'



REAR VIEW

SPEED OF VEHICLE IS 0-5MPH  
 CONTROLLED BY HAND  
 THROTTLE & SCR DRIVE.

DPR266-537

Figure 3-1 - Assembly Drawing of MERV

TABLE 3-1 KEY TO ASSEMBLY DRAWING (FIGURE 3-1)

<u>Item No.</u>	<u>Description</u>
1	Motor, 3 H.P., 36 V DC
2	Control, 3 H.P., 36 V DC
5	Chain Drive
6	Cable, Headlight #16-3 Conductor
7	Hose, Conduit, 3/4" I.D. x 1 1/8" O.D.
8	Circuit Breaker
9	Cable, Power, #2-2 Conductor
10	Hose, Conduit, 1 1/2" I.D. x 1 7/8" O.D.
11	Lights (front and rear)
12	Battery Cell
13	Housing, Battery
14	Cover, Battery
15	Fire Extinguisher
16	Canister, Cable Reel
17	Horn
18	Reflector, Red
19	Wheel Assembly
20	Trailer Hitch
21	Hoisting Bar Assembly
22	Mirror
23	Sampling Probe
24	Body, Lower, ABS Plastic
25	Body, Upper, ABS Plastic
26	Bearing
27	Transmission
28	Cover, Rear
29	Seat
30	Operating Control, Right Side
31	Operating Control, Left Side
32	Emergency Brake Handle
33	Shifting Handle
34	Approval Plate
35	Odometer
36	Battery Gauge

TABLE 3-2 - COMPARISON OF MERV VEHICLE  
DESIGN AND PERFORMANCE SPECIFICATIONS

	<u>Bureau Spec</u>	<u>MERV</u>
Length	100 in. max	100 in.
Width	56 in. max	56 in.
Height	30 in. max	32 in.
Obstacle Crossing	12 in. dia. log	12 in. dia. log
Ground Clearance	5 in.	6 in.
Tires	Low pressure	Low pressure
Wheels	Multiple wheels	6 wheels
Motor	3 HP min continuous	3 HP continuous
Steering	Independent control right & left sides	Independent control right & left sides
Speed	0-7 mph	0-6 mph
Speed Control	SCR, or equivalent	SCR
Turning Radius	Turn in own length	Turn in own length
Brakes	All wheels	All wheels
Color	High visibility color	Yellow
Accessories	Trailer hitch, lifting lugs	Trailer hitch, lifting lugs
Dead Weight	1500 lb (including batteries)	1690 lbs
Gross Weight	2500 lbs	2500 lbs
Nominal Payload	2 man crew Life support Gas detection instru- mentation Trailer plus victims Communications (10,000 ft)	2 man crew Life support Gas detection instru- mentation Trailer plus victims Communications (10,000 ft)
Permissibility	Schedule 2G	Schedule 2G
Grade	45%	45%

\* Modified to 34 inches to accommodate lead-acid batteries.

\*\* Modified to 2100 lbs to accommodate lead-acid batteries.

Essentially two variances were necessary in the initial MERV: overall height and weight. Neither of these were significant to prevent meeting performance specifications, nor to visibly place restrictions on utility. On the other hand, additional clearance to six inches was accomplished in the design. This is particularly important in traveling mine railways and general obstacles.

When the MERV mission was later modified to a 4-hour mission, and lead-acid batteries substituted for the silver-zinc cells, the weight and height further increased.

### 3.1.1 General Design Considerations

The goal for the design team was to develop a unit that would not only meet the specifications of Table 3-2, but do so in a vehicle having a high degree of mechanical reliability and a reasonable degree of comfort for the crew. The missions would likely be hazardous and possibly lengthy. Thus, to keep crew fatigue to a minimum, the operation of the vehicle was to be simple and dependable, and the crew members positioned for comfort.

Mobility analyses were conducted by Delco Electronics to provide data for design selections and assurances that the final design would perform as expected. Models and mock-ups were employed to consider the human engineering aspects of the initial design, with minor changes made as a result of studies on the actual unit.

#### 3.1.1.1 Selection of the Basic Configuration

The final design of the MERV followed closely that proposed in answer to the Bureau's RFP. However, this design and several variations were first checked by Delco, developing by computer analysis the expected performance parameters of each variation under what would be considered general and then difficult mine conditions.

The mobility analysis considered four design variations, with the MERV characteristics and parameters listed in Table 3-3, in comparing basic 6- and 8-wheeled variations. The assumptions made on the analysis were as follows:

Vehicle length	100 inches
Vehicle width	56 inches
Vehicle drive reduction	7 mph @ 1750 rpm - 80% efficient
Vehicle live load	500 lbs
Vehicle dead weight	100 lbs

TABLE 3-3 - MERV PARAMETERS CONSIDERED IN INITIAL MOTION RESISTANCE EVALUATION

Configuration No.	#1	#2	#3	#4
Number of Wheels	6	6	6	8
Axle Spacing	28 inch	34 inch	30 inch	25 inch
Tire Size	21 x 11-8	26 x 12-12 (4 ply)	26 x 12-12 (2 ply)	21 x 11-8
Tire Width	11.5 inch	12.9 inch		11.5 inch
Tread Width	44.5 inch	43.3 inch	43.3 inch	44.5 inch
Tire Radius (loaded)	8.6 inch	12.2 inch		8.6 inch
Weight Distribution (% - Front to Rear Axle)	(a) 43, 34, 23 (b) 23, 34, 43 (c) 33 1/3 all	(a) (b) Same as (c) #1	(a) (b) Same as (c) #1	(a) 20,20,30,30
Dead Weight	(a) 1250 (b) 1500 (c) 1700	(a) (b) Same as (c) #1	(a) (b) Same as (c) #1	(a) (b) Same as (c) #1

Trailer live load	500 lbs
Trailer tire size	12 x 11-6
Trailer weight distribution	50% each wheel

The analysis covered the vehicle tire-soil relationships, trailer tire-soil relationship, obstacle height and resistance, and the effect of gross vehicle weight, weight distribution, and number of wheels, on steering. The details of this study are included in the Appendix.

In summary, configuration #3 (Table 3-3) proved to be the best compromise. The 8-wheeled unit, #4, gave the least soil resistance; the the 6-wheeled configuration with 21 x 11-8 tires, the least steering resistance. The analysis indicated that the performance of the smaller tire, which was on both units, was better than the larger ones because, at comparable load and inflation pressure, its greater deflection resulted in larger ground-contact area. Minimum weight was obviously desirable; however, the weight distribution did not appear significant within the limits examined.

The larger diameter wheels (26 x 12-12), on the other hand, were clearly superior in negotiating obstacles. The obstacle height and resistance analysis assumed the obstacle contact height as the height of a square or rectangular timber, or the nominal point of tangency for a log, round section, or an included flat plate. The analysis was done on a per-wheel basis and considered two wheels in contact with the obstacle. As expected, the results showed that the obstacle negotiation offered substantially more motion resistance than did the tire-soil relationship, and that the coefficient of friction between the tire and obstacle ( $\mu$ ) was a significant factor. It also showed that the advantage of a large diameter tire over the smaller tire at a 1750-pound gross vehicle weight (G.V.W.) increased rapidly as obstacle height increased and the coefficient of friction decreased. This advantage, however, was less significant at 2200 lb G.V.W.

The analysis also showed that a 4-ply 26 x 12-12 tire gave considerable soil and steering resistance. The 2-ply 26 x 12-12 diameter tire, on the other hand, showed that its greater deflection, and thus larger footprint area, significantly offset the advantages in soil and steering resistance of the smaller tire while still retaining the superiority in negotiating obstacles.

As a result of the analysis, the 6-wheeled variation with 26 x 12-12 tires was selected as the basic configuration.

### 3.1.1.2 Weight Distribution

A more detailed computer analysis on the capability of the 6-wheeled MERV to negotiate obstacles resulted in guidelines for weight distribution on the vehicle, and a decision to change the initially planned gear ratio of 22.89:1 to a larger 30:1. The analysis considered both the effect of flexible tires and the geometric constraints of the vehicle. More accurate results were yielded by this system than by the more classical rigid wheel approach.

In the analysis, tire radii (and drive motor torque) were alternately adjusted to correspond to changing ground and obstacle loads caused by chassis inclination, center of gravity (C.G.), location, obstacle contact point (height and wheel set), drive motor reaction torque and other considerations. The analysis assumed the following:

- One set of wheels (one axle) was considered to be in contact with the obstacle.
- One set of wheels was considered to be in contact with the ground.
- One set of wheels was considered to be in contact with neither the ground nor the obstacle.
- All wheels were considered to be driven.
- The obstacle was not contacted by more than one set of wheels at a time.
- Flat plate deflection rates at the ground and at the obstacle.
- A state of incipient movement over the obstacle.
- No suspension system or chassis deflection.

To evaluate the effect of various parameters on the performance, the program inputs included the following: (Values for the most favored definition of the vehicle system at the time of the analysis are shown in parentheses.)

- Vehicle weight(s)
- Undeformed tire radius (12.8 inches)

- Nominal tire deflection (1.58 inches)
- Vertical and longitudinal c.g. location information (Vertical - 13 inches)
- Wheelbase (60 inches)
- Obstacle height increments
- Motor reduction ratio and efficiency (0.8)
- Coefficient of friction at the obstacle ( $\mu = 0.8$ )
- Wheel set (axle) in contact with obstacle

This analysis results in a conservative design approach since it considers only a static condition; i.e., acceleration and inertia. Other dynamic effects are not included.

The more salient points were calculated. These included torque requirements, coefficient of friction necessary at the surface, and chassis inclination. The last identifies the set of wheels providing tractive effort on the surface.

In the cases examined, using these inputs, some observations can be made:

- As the center of gravity was moved rearward, it became less difficult to negotiate an obstacle with the front and middle wheels and increasingly more difficult with the rear wheels. The front wheels are least sensitive to c.g. location and are easiest to get over the obstacle. The middle wheels are most sensitive since the obstacle can be directly under the c.g. At a 5 3/4 inch obstacle height and a 43% front axle loading, the contact point is almost directly under the c.g. The obstacle height is sufficient to cause the front wheels to be in the air and the rear wheel load to be sufficiently reduced to require an unrealistic coefficient of friction for the necessary tractive effort.

A front axle loading greater than 40% should be avoided because of this condition. To further emphasize this point, the vehicle middle axle capability was reduced almost 50% when a 42% front axle load was compared to a 40% load.

- The middle and rear wheel performance are limiting factors in obstacle negotiation. As a function of traction, for surface coefficients of friction up to 0.59, the 20% front axle loading is advantageous. A 25% loading is best for ranges between 0.59 and 0.94, while a 30% loading is better only above  $\mu = 0.94$ . With a 10% front axle loading, the rear wheel obstacles limit maximum obstacle heights to approximately 7.6 inches. It would seem, therefore, that for the cases examined, an optimum weight distribution would be a front axle loading of 20 to 25%. Maximum obstacle contact point as constrained by vehicle configuration would then range between 8.4 and 9.0 inches at  $\mu = 1.0$ .
- A larger gear ratio is necessary to develop adequate torque to take full advantage of the vehicle capability. The drive motor is current limited and the smaller reduction ratio (22.89:1) initially planned would only permit negotiation of an obstacle with a 5 1/2 inch contact point. A gear ratio of approximately 30:1, however, would develop sufficient torque to negotiate the obstacles with vehicle contact points in the 8.4 to 9.0 range under the conditions described above.

### 3.1.1.3 Operator Positioning

The contract Scope-of-Work suggested that the low-seam configuration of the MERV should position the two operators prone on the deck of the vehicle to give suitable clearance. Our early analysis of the positioning of the operators indicated that the prone position, even with suitable contouring of the deck, would be uncomfortable for the operators for even a short mission. Furthermore, when the operator is equipped with the necessary equipment (e.g., face piece, head guard, and cap lamp) the prone position would severely restrict vision as well as giving extreme neck discomfort. Thus, every effort was made to design the vehicle with both operators seated upright, or nearly so, with the final design being one in which the operator was seated upright, while the assistant was positioned prone to the right of the operator. Surprisingly, in this configuration, it is the man lying prone who is the limiting clearance factor, rather than the seated driver. A wooden mock-up of the cockpit area, employed to establish leg room, positioning of the controls and instruments, and seat design, arrived at the

minimum space requirements for the driver. Comfort and clearance with full life support equipment were the ultimate determining factors.

Consideration was given to several alternative placements. Obvious space requirements precluded the possibility of seating the operators low between the wheels, and the clearance requirements of 48 inches made it impossible to seat them on the deck. A preliminary analysis indicated that the most efficient use of the space on the MERV could be achieved by placing the two operators one behind the other as in a snowmobile. The driver would sit low in the center-forward section of the vehicle with his assistant somewhat higher on a stepped seat in order to see over the driver. This arrangement would give a low overall configuration, allow the driver to sit astride the controls, allow room on both sides of the vehicle for equipment or batteries, and leave space behind the operators on the deck for subassembly components such as life support.

Further analysis showed, however, that positioning the two operators in tandem would interfere with the space necessary for the drive train components. Seating the driver essentially on the floor, and placing his assistant somewhat higher, as for example on the battery case, made the concept somewhat more feasible in terms of available drive-train space, but exceeded the allowable low-configuration height limits for the assistant.

By positioning the operators as we have, with the driver seated upright and the assistant lying prone, we believe we have eliminated the necessity for a high-seam configuration. The contract Scope-of-Work had suggested a high-seam design in which the two operators would be seated on the deck for comfort. Our low-seam design, however, has positioned the driver comfortably and would give the assistant the option of either lying down or sitting upright on the rear deck of the MERV, depending on the clearance.

### 3.1.2 Frame and Wheel Assembly

The frame assembly for the MERV is mounted internal to the plastic body, resulting in a water-tight body construction. The frame, shown in Figure 3-2, with key given in Table 3-4, is a welded box ladder construction -- a design proven by the automotive industry. The outside frame members are constructed of aluminum channel. Tubular cross members, similar to those used in lightweight racing cars, were used for lateral support and suspension for the six wheels. This type of frame is strong enough to support heavy loads and yet flexible enough to maintain its shape during heavy stress.

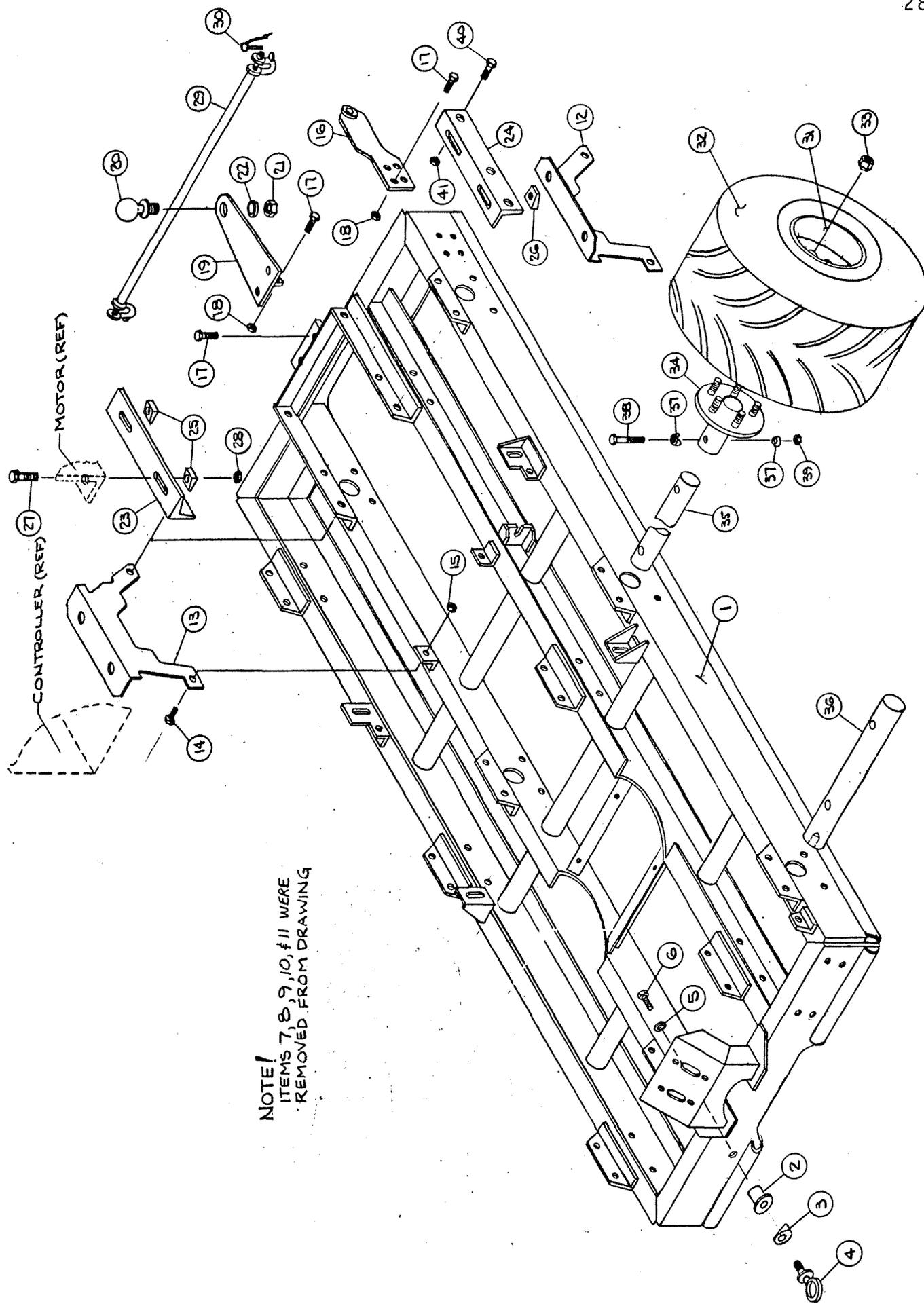


Figure 3-2 - MERV Frame, Wheel & Axle Components

TABLE 3-4 - KEY TO FRAME ASSEMBLY (FIGURE 3-2)

<u>Component Number</u>	<u>Description</u>	<u>Component Number</u>	<u>Description</u>
1	Frame Assembly	23	Motor Support (Right)
2	Forward Hitch	24	Motor Support (Left)
3	Forward Hitch Washer	25	Support Washer (Right)
4	Forward Hitch Eyebolt	26	Support Washer (Left)
5	5/8" diameter Flat Washer	27	1/2-20 x 2" Hex Head Bolt
6	5/8-11 x 1 1/4" Hex Head Bolt	28	1/2-20 Lock Nut
12	Controller Housing Mounting Bracket, LH	29	Stabilized Lift Assembly
13	Controller Housing, Mounting Bracket, RH	30	Locking Pin
14	1/2-13 x 1" Hex Head Bolt	31	Wheel
15	1/2-13 Lock Nut	32	Tire
16	Lift Bracket Assembly	33	Lug Nut
17	3/8-16 x 1" Hex Head Bolt	34	Axle Hub Assembly
18	3/4-16 Locknut	35	Axle
19	Hitch Plate Assembly	36	Axle (Left Front)
20	Trailer Towing Ball, 1 7/8" diameter	37	Washer
21	3/4-10 Nut	38	3/8-24 x 3 1/2" Hex Head Bolt
22	3/4 Spring Lockwasher	39	3/8-24 Lock Nut
		40	1/2-13 x 1" Hex Head Bolt
		41	1/2-13 Lock Nut

The 12-inch wheels, with 26 x 12-12 2-ply tires, are mounted on six steel axle members. Support at the frame is provided with twelve flange bearing supports.

Lifting lugs (Component 29, Figure 3-2) are provided for lowering the vehicle on end down a shaft. In addition, a hitch support and towing ball (Component No. 19 and 20) are included for accommodating the trailer.

### 3.1.3 Drive Train Components

The drive train for the MERV consists of a 36 V lead-acid battery, SCR controller, 3 HP continuous-duty DC motor and transmission, with chain and sprocket transmission of power to all six wheels. A gear ratio of 30:1 provides adequate torque. The general positioning of the major components was previously shown in the general assembly drawing (Figure 3-1). This section discusses the individual drive train components, with the exception of the battery, and their installation within the MERV. The battery is taken up separately in Section 3.2.

#### 3.1.3.1 Motor

The motor is a MESA approved 3 HP, 36 volt DC continuous duty mine tractor motor made by Reliance Electric Company. The specifications are given in Table 3-5.

TABLE 3-5 - SPECIFICATIONS FOR MERV MOTOR

Motor, 3 HP, 36 V.D.C., 80 amps full load  
 1750 RPM, Continuous duty, series wound, tractor duty, Type T  
 Standard single shaft extension  
 Rotation clockwise facing commutator end  
 Frame: XL216A  
 TEFC, B.O.M., Schedule 2G  
 Dimension Sheet 69203-421  
 Cable, 8 ft long. Size #4-4 conductor, 1.27 in. O.D., flame  
 resistant per MESA Schedule 2G  
 Conduit hose, 6 ft long. Size 1 1/2 in. I.D. x 1 7/8 in. O.D.,  
 flame resistant per MESA Schedule 2G  
 Wiring Diagram W/D 12649-A  
 Mechanical Specs L 216A-338  
 Electrical Specs 106102-206494-306105  
 X/P 902 Extension 68

The motor is mounted on the transmission to the rear of the operator. Power is transmitted to the transmission through a chain.

Overload protection is provided in the controller. The protection provides a 5-second cut-off at 262 amps, but will allow 210 amps for one minute for peak loading during difficult maneuvers. The stalled or locked motor load is 970 amps.

### 3.1.3.2 Transmission

A dual planetary transmission -- a unique design made exclusively for all-terrain vehicles -- provides individual control of the left and right side sets of wheels. The transmission, made by Borg-Warner, provides power to the wheels, and steering and braking at any speed in both forward and reverse.

The individual drive components for transmitting power from the motor to the wheels is shown in Figure 3-3, with the key given in Table 3-6. Power from the motor is transmitted through a chain drive. A primary chain (Component 51) transmits the power from the transmission to the rear set of drive-wheel sprockets, and secondary chains (Component 52) transmit the power to the middle and forward wheels.

All sprockets were initially specified as high-strength aluminum alloy construction (Type 7075-T6). As a result of testing, however, all the drive sprockets were converted to steel.

The transmission provides steering, braking, and forward and reverse capability to the vehicle. Steering is of the slide or scuff-type and is accomplished with the two control handles, shown as Component 20 in Figure 3-4. The key to Figure 3-4 is given in Table 3-7.

The left-hand lever controls the three wheels on the left side of the vehicle; the right-hand lever, the three wheels on the right side. Pushing a control lever forward engages a clutch with an immediate power response to wheels on the respective side. Pulling a control lever back activates the internal band brake, thus disengaging the power and locking the wheels. By maintaining a lever in the central position, neither the clutch nor the brakes are actuated and, thus, the wheels for that respective side "float" or are in a neutral position.

Figure 3-5 shows a view of the control levers equipped with the hand-operated speed control and hinged to allow them to tilt forward to make it easier for the driver to get in and out of the vehicle.

The transmission can be reversed by moving the two small shifting ball levers located in front of the two control levers. The vehicle can be placed in reverse by reversing

TABLE 3-6 - KEY TO DRIVE ASSEMBLY (FIGURE 3-3)

Component Number	Description	Component Number	Description
1	Odometer	33	1/4-20 Eyebolt
2	Odometer Cable	34	1/4-20 Lock Nut
3	Cable Housing	35	Brake Return Spring
4	Drive Cable	36	Axle Bearings
5	Drive Gear	37	1/2-20 x 2 in. Hex Head Bolt
6	Cable Mounting Bracket	38	1/2-20 Locknut
7	Right Angle Drive	39	Idler Sprocket
8	Brake Equalizer	40	Transmission Idler Bracket (Left)
9	Adjusting Yoke	41	Transmission Idler Bracket (Right)
10	Adjusting Rod	42	3/8-16 x 1 1/2 Hex Head Bolt
11	5/16-18 x 1 1/4 Hex Head Bolt	43	3/8 Medium Lockwasher
12	5/16-18 Locknut	44	5/8-18 x 2 1/4 Hex Head Bolt
13	5/16 Dia SAE Flatwasher	45	5/8-18 Locknut
14	1/8 x 1 in. Cotter Pin	46	5/8 SAE Flatwasher
15	5/16 Dia Fenderwasher	47	Front Drive Spool Assembly
16	3/8 Dia Clevis Pin	48	Center Drive Spool Assembly
17	Emergency Brake Caliper Assembly	49	5/16-18 x 2 1/4 Hex Head Bolt
18	3/8 Dia SAE Flatwasher	50	Rear Drive Spool Assembly
19	Caliper Mounting Bracket (Right)	51	Primary Chain
20	Caliper Mounting Bracket (Left)	52	Secondary Chain
21	Emergency Brake Lever Assembly	53	Master Link
22	1/4-20 x 3/4 Hex Head Bolt	54	3/8-24 x 3 1/2 Hex Head Bolt
23	1/4-20 Hex Nut	55	Emergency Brake Release Handle
24	Brake Spacer	56	#10-32 Closed Eyebolt
25	U-Bolt	57	#10-32 Open Eyebolt (Modified)
26	Brake Ratchet	58	#10-32 Nut
27	3/8-24 x 1 1/4 Hex Head Bolt	59	#10-32 Lock Nut
28	3/8-24 Locknut	60	Chain
29	5/16-18 x 3/4 Hex Head Bolt	61	Sprocket
30	5/16-18 Locknut	62	Sprocket
31	Ratchet Return Spring	63	Drive Bushing
32	Handgrip	64	Driven Bushing

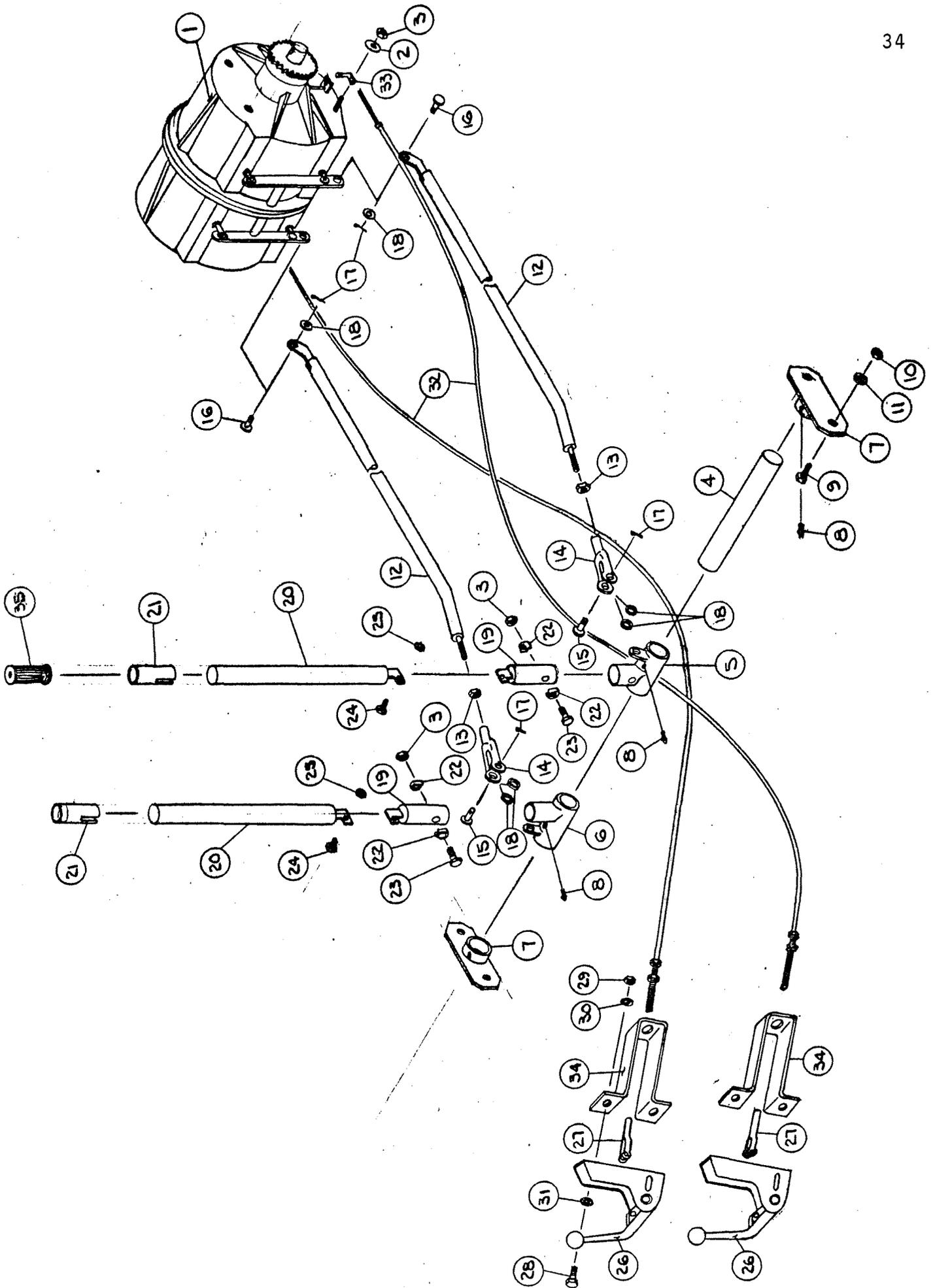


Figure 3-4 - MERV Steering and Transmission Components

TABLE 3-7- KEY TO TRANSMISSION COMPONENTS (FIGURE 3-4)

<u>Component Number</u>	<u>Description</u>	<u>Component Number</u>	<u>Description</u>
1	Transmission, Modified	19	Lower Steering Lever Assembly
2	3/8 Dia x 1 1/4 O.D. Bellville Washer	20	Upper Steering Lever Assembly
3	3/8-16 Locknut	21	Steering Locking Sleeve
4	Steering Horizontal Bar	22	Washer
5	Steering Receptacle, Left	23	3/8-16 x 2 3/4 Hex Head Bolt
6	Steering Receptacle, Right	24	1/4-20 x 3/4 Hex Head Bolt
7	Steering Mounting Bracket	25	1/4-20 Lock Nut
8	Grease	26	Shift Lever Modified
9	5/16 x 24 x 1 in. Hex Head Bolt	27	Yoke, Modified
10	5/16-24 Lock Nut	28	5/16-24 x 3/4 Hex Head Bolt
11	5/16 SAE Flat Washer	29	5/16-24 Nut
12	Steering Road Assembly	30	5/16 Type B Flat Washer
13	3/8-24 Nut	31	5/16 Spring Lockwasher
14	Adjustable Yoke (R.H.)	32	Transmission Shift Cable
15	3/8 Clevis Pin	33	Swivel Joint
16	3/8 Clevis Pin, Altered	34	Cable Mounting Bracket
17	1/8 x 1 in. Cotter Pin	35	Hand Grip
18	3/8 SAE Flatwasher		

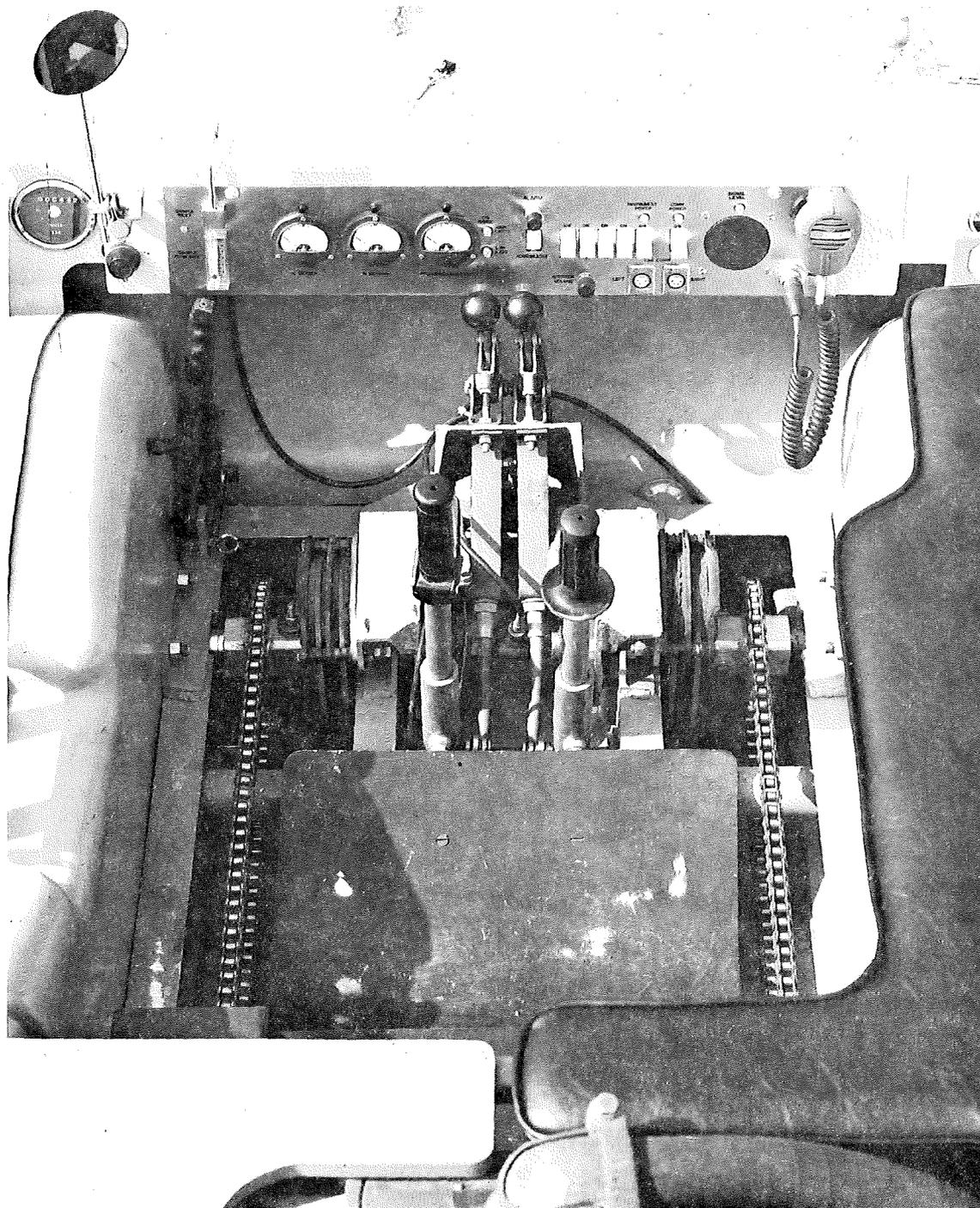


Figure 3-5 - View of Control Levers

both sets of wheels, or is able to spin by reversing only one set and running the two sets of wheels in opposition to one another.

A problem with shifting the transmission from forward to reverse was noted in the original design, which was aggravated when MERV-1 was modified to accept the heavier lead-acid batteries. An analysis of the problem indicated that the difficulty was due mainly to the requirement for an extremely tight drive-train system. In conventional drives, there is slack allowable in the drive chains. This allows for some movement of the transmission-engaging sprockets, and forward-to-reverse shifting is accomplished without apparent problems. In the MERV, because of the weight, the primary drive chains must be maintained tight. If not, under situations of high torque, such as turning, chain slippage occurs.

The "fix" was to install a slotted drive-pin system at the main drive sprocket, thus allowing some play in the chain drive between the transmission and the main drive sprocket. This, in turn, allowed movement in the reversing gears which facilitated the engaging and disengaging action.

An analysis of the torque requirements of the MERV by ATV showed that the transmission would meet all but the most severe conditions without stress.

Torque requirements calculated for sandy soil conditions, the worst case, are as follows:

<u>Condition</u>	<u>Calculated Torque (inch pounds)</u>
Level running	235
Climbing 45% grade	1280

Although the 1280 figure exceeds the capability for the transmission, the overload would be for a short duration, and the penalty would only be band slippage caused by overheating.

At the suggestion of MESA personnel, we gave considerable thought to a request that the hand controls on the vehicle be modified so that forward, straight-line motion could be maintained with a single hand on the controls. We came up with no modification that, in our mind, would work satisfactorily.

Various locking techniques for tying the two control levers together were considered and rejected. Because of the frequency with which minor direction corrections must be conducted, a locking bar or similar device would be a nuisance to engage and disengage.

For a time, the answer appeared to be the addition of extensions to both levers that would almost meet midway between the levers in such a manner that one hand would overlap the junction. A twist of wrist, therefore, would apply pressure to one or the other control lever to drive one side in preference to the other. It would not, however, allow enough travel to apply braking action to one side and maintain drive on the other -- the action generally required to make a direction change.

Problems with the speed control and communication buttons were final complications which influenced us to leave things status quo. The speed control is integral to the left lever and the communication button integral to the right. Both of these, and at least the speed control, would have had to be incorporated into any one-hand control systems to be of any use. Although ultimately the communications button was removed from the steering lever, the speed control and steering problems were still, in our opinion, insurmountable.

### 3.1.3.3 Controller

An SCR drive controller provides control action to the motor over a continuous speed range in both forward and reverse directions. Produced by Sevcon, Inc. of Burlington, Massachusetts, the drive control electronics consists basically of a commercial solid-state, DC motor controller which has been modified to match the vehicle mechanical and electrical interfaces.

The controller components consist of an accelerator unit, master logic module and contactor panel. Speed of the vehicle is controlled by a flexible cable from the right-hand control lever to the accelerator unit inside the control box. Variable speed control is obtained by means of a potentiometer mounted in the accelerator unit. Depression of the pedal provides a variable voltage signal to the master logic module. As the pedal is depressed, the voltage in the wiper falls from 12 to 6 volts, indicating the required speed. Minimum speed is when the signal is 12 volts; maximum, when the signal is 6 volts.

The arrangement of the master logic module on the heat sink with component call-out, is shown in Figure 3-6. A circuit is provided which controls the maximum permissible current during the pulsing mode. Current limit can be adjusted by a resistor, which is mounted on the master logic module, up to the maximum permissible current for the equipment. This has been set for 162 amperes. An automatic emergency disconnect, which consists of a relay and timer module, provides for a fail-safe system.

- (4) #6-32UNC x 3/8 LG. RD. HD SCR
- (4) #6 FLAT WASHER
- (4) #6 LOCKWASHER

- (4) #6-32UNC THREADED ROD 5 1/2 LG
- (4) #6-32 KEP NUTS

INDUCTOR TERMINAL BRACKET B20217

- (1) 1/4"-20UNC x 1" LG HEX HD STAIN. STL
- (2) 1/4"-20 LOCK NUT "
- (4) 1/4" FLATWASHER "
- (1) 1/4" LOCKWASHER "

SCR-3 ASSEMBLY C20225

(3) CAPACITOR

CAPACITOR BUS BAR B20234 (2 REQ'D)

CAPACITOR HOLD DOWN B-20210 (2 REQ'D)

- (2) 1/4"-20 x 1" LG H.H. STAIN. STL
- (4) 1/4"-20 LOCKNUT "
- (8) 1/4" FLATWASHER "
- (2) 1/4" LOCKWASHER "

INDUCTOR B20214

SCR-2 ASSEMBLY C20232

NOTE  
REFERENCE  
SEVCON INC. DWG  
C-20215

NERVE CENTER ASSEMBLY C-20233

SCR-1 & D42 ASSEMBLY C20228

BASE PLATE C20203

CSK1650-512

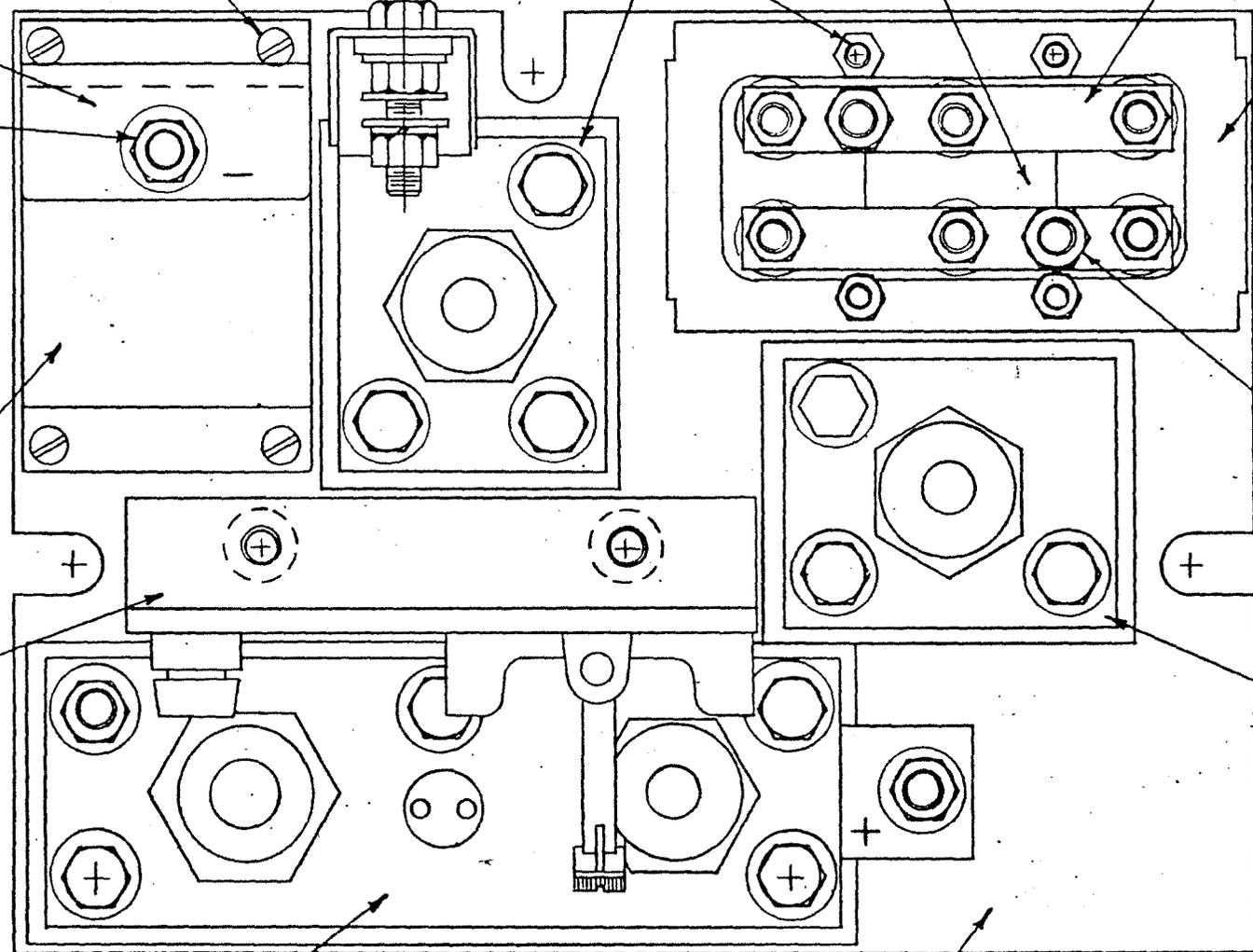


Figure 3-6 - Controller Master Logic Unit

Two contactors are provided: a main contactor and bypass contactor. The main contactor operates during normal start-up and vehicle operation. The bypass contactor connects the drive motor directly across the power supply for full speed conditions.

A MESA Schedule 2G approved circuit breaker is provided between the battery and controller. This unit provides easy on-off control and overload protection.

The arrangement of these various components within the controller, along with the fuel gauge and light switches, is shown in Figure 3-7. The controller housing, shown in Figure 3-8, is constructed of steel, and the enclosure cover (Figure 3-9) of aluminum. The design conforms to MESA Schedule 2G specifications.

#### 3.1.3.4 Brakes

The MERV has braking action in the transmission, used primarily for steering, and a hand-operated dual-disc brake located on the left forward area of the driver compartment. Pulling the steering levers back disengages the power in the transmission and applies braking action. The hand-operated emergency brake is equipped with an equalizer mechanism which applies equal braking pressure on both the left-hand and right-hand drive wheels. The emergency brake should always be used when descending a steep grade or when attempting to shift gears on a steep grade. A warning light in full view of the operator indicates when the emergency brake is ON.

#### 3.1.3.5 Wiring and Permissibility

The wiring of the MERV was conducted by MSA personnel according to Schedule 2G regulations. A schematic showing the wiring is given in Figure 3-10, with the basic wiring diagram shown in Figure 3-11.

Periodic inspections were made by the BuMines Approval and Testing Group of the Pittsburgh Technical Support Center, during which permission was granted on the elimination of a connector between the battery and controller with the relay unit present, and approval given for double-bolted battery terminals.

#### 3.1.4 Body Design and Construction

The MERV body is vacuum-formed of Royalite 20, an ABS thermoplastic. The body is formed in two sections -- top and bottom -- which are glued and stapled together. Yellow

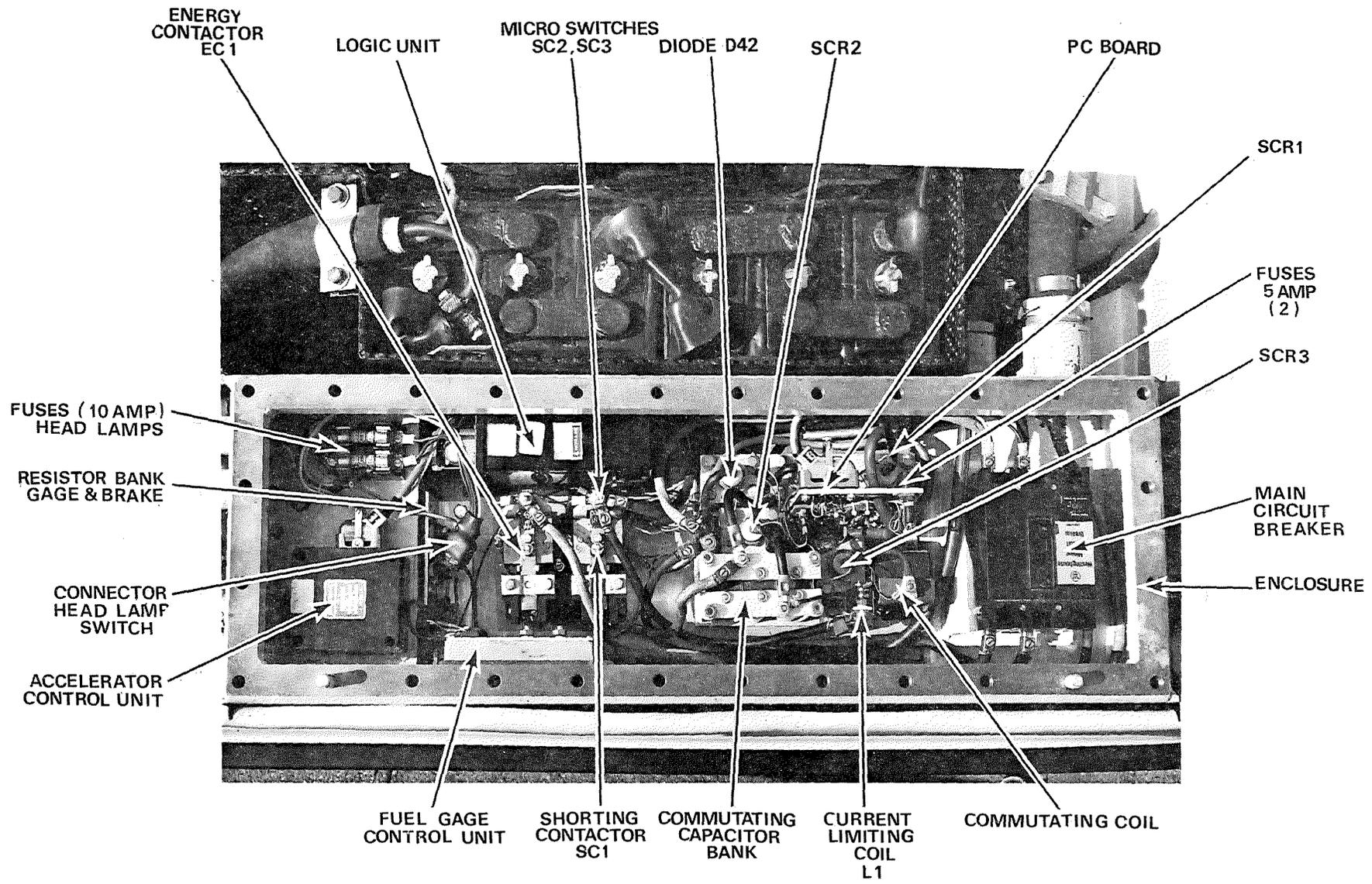
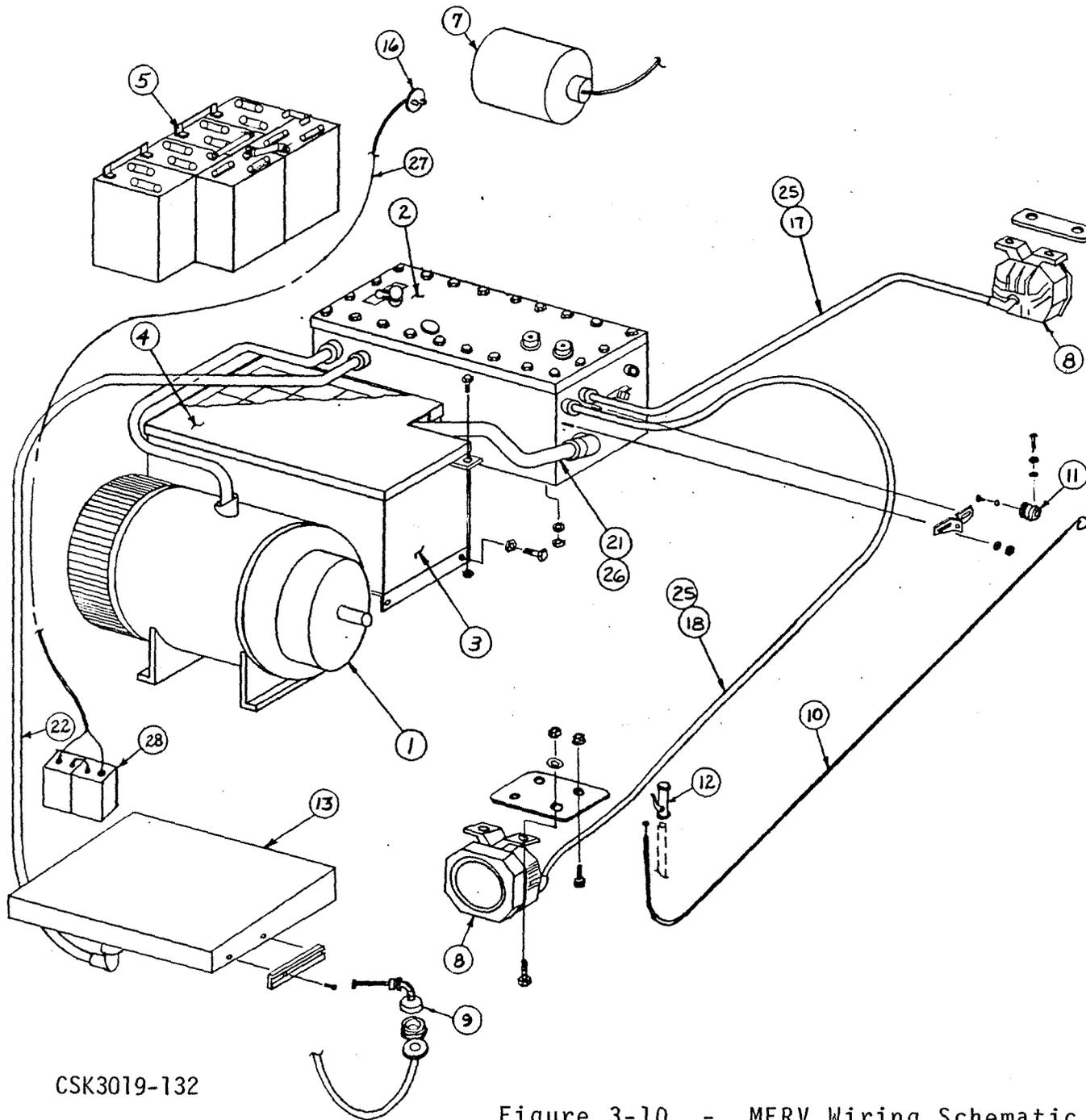


Figure 3-7 - View of Controller Showing Arrangement of Components







PARTS LIST				
ITEM NO.	PT. NO. DWG. NO.	EQSD.	ATV No.	DESCRIPTION
1	DPR 782 - 2490	1	975-10-001	MOTOR
2	DPR 782 - 2645	1	975-23-001	CONTROLLER ASSY
3	CPR 266-411	1		BATTERY HOUSING
4	CPR 266-412	1		BATTERY COVER
5	APR 266-410	1		BATTERY ASSY.
7	DPR 782 - 2680	1	975-10-009	COMMUNICATION CABLE/HOUSING
8	DPR 782 - 2488	2	975-10-002	HEADLIGHT
9	~	1	975-10-010	INSTRUMENT PROBE
10	DPR 782 - 2687	1	975-23-003	CONTROLLER CABLE
11	DPR 782 - 2686	1	975-23-005	CONTROLLER CABLE SPOOL
12	~	1	295-11-014	THROTTLE LEVER ASSY.
13	~	1	975-23-008	INSTRUMENT PANEL HSB.
16	~	1	975-10-015	COMMUNICATION CONNECTION
17	DPR 782 - 2643	1	975-10-014	REAR HEADLIGHT CABLE
18	DPR 782 - 2643	1	975-10-015	FRONT HEADLIGHT CABLE
21	22597	1	975-10-018	CONTROLLER TO BATTERY
22	~	1	975-10-019	CONTROLLER TO INSTRUMENTATION CABLE
25	600244	AS REQD.		HOSE, CONDUIT 3/4" I.D. x 1 1/8" O.D.
26	600247	AS REQD.		HOSE, CONDUIT 1 1/2" I.D. x 1 7/8" O.D.
27	DPR 782 - 2679	AS REQD.		CABLE, BATTERY TO COMM. REEL
28	625666	2		BATTERY, 12 VOLT
29				
30				

NOTE: BATTERY COVER IS SUPPLIED WITH BOLT HOLD DOWN. CUSTOMER SHOULD FURNISH PADLOCK FOR COVER HOLD DOWN.

NOTES:

- ONE OF THE THREE CONDUCTORS OF THE HEADLIGHT CABLE IS CUT OFF INSIDE CONTROLLER & INSIDE HEADLIGHT HOUSING. THE ENDS ARE TAPED & INSULATED & ONLY TWO CONDUCTORS ARE CONNECTED.
- TWO OF THE MOTOR CABLE CONDUCTORS ARE SPLICED TOGETHER & INSULATED INSIDE THE CONTROLLER (RED & BLACK). THE WHITE (-) AND GREEN (+) CONDUCTORS ARE CONNECTED TO PROPER TERMINALS IN CONTROLLER.
- INSTRUMENT CABLE IS 19 STRANDS OF #18 AWG VINYL COATED WIRE.

CSK3019-132

Figure 3-10 - MERV Wiring Schematic

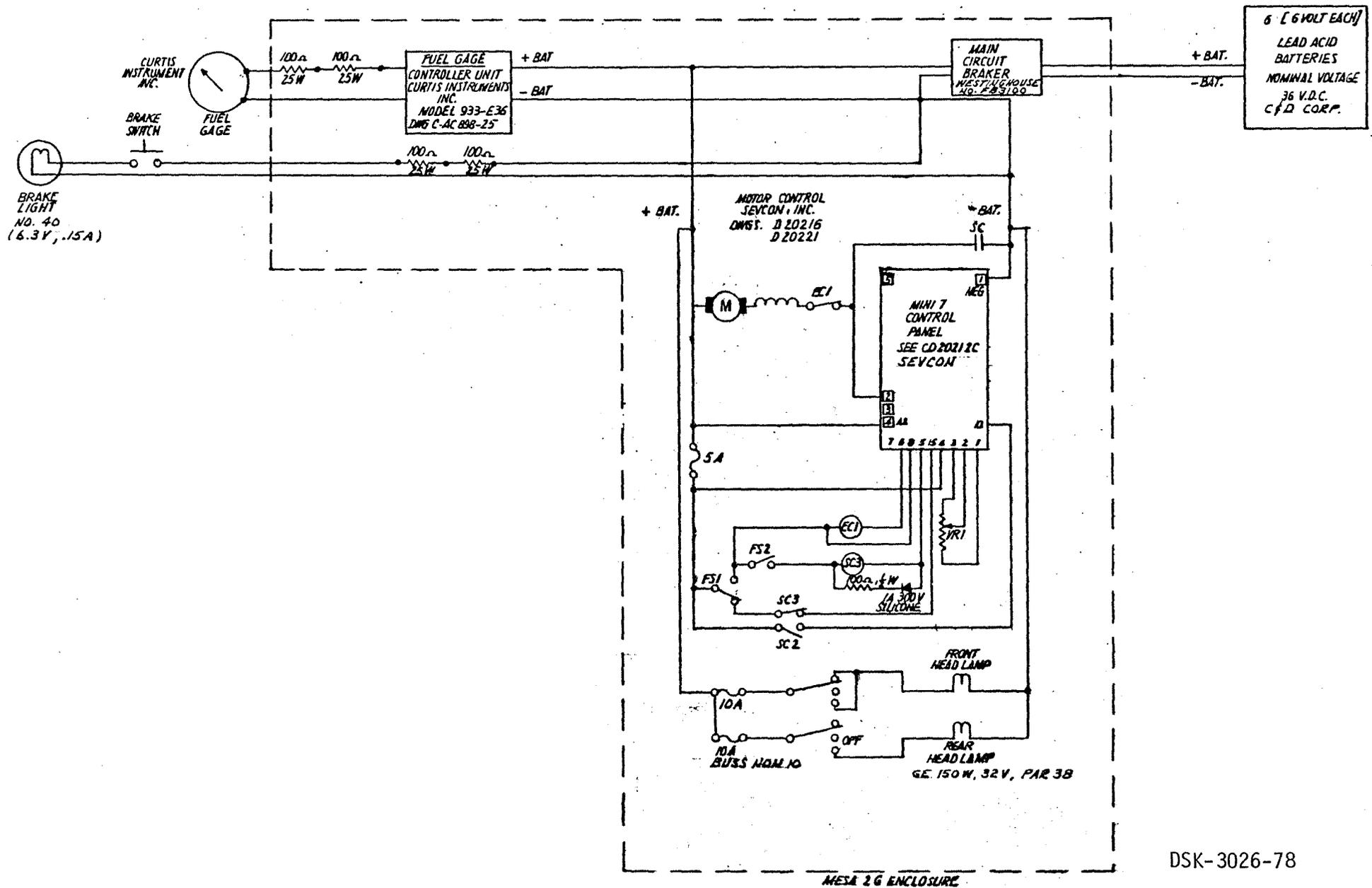


Figure 3-11 - Wiring Diagram of Basic Components

DSK-3026-78

is blended into the plastic sheet when it is manufactured to give a long-lasting, high-quality reflective color.

A schematic of the MERV body components is shown in Figure 3-12 with the key given in Table 3-8. The lower body section (Component 1) is constructed to accept the internal frame to achieve a water-tight body construction. The front and rear body angles, coupled with the wheel placement, allow the vehicle to approach and negotiate most obstacles without making contact before the wheels, thus preventing hang-ups.

The upper body (Component 2) contains the control-panel housing and is designed to fit the contours of the lower section. When fastened to the lower body, this, along with the rolled edge, provides strength and rigidity.

The floor pan (Component 3) is designed to protect the driver from the drive chains and sprockets and to make use of all available depth in the body to achieve a low drive profile. Padding (Components 28 and 29) provides comfort for the driver and for the assistant (Component 32).

The upper deck has been fabricated from plywood with metal frames supports. Padding is included for the comfort of the assistant.

### 3.1.5 Performance and Recommendations

The performance of the basic vehicle, based on the design initially developed, was more than adequate to meet the performance specifications of the contract. Above-ground performance tests at MSAR and in-mine tests showed that the vehicle had adequate power and was suitable designed to negotiate logs, flooded areas, rail haulageways and steep grades.

The in-mine demonstration for the lead-acid-battery modified version of the MERV was conducted on 15 October 1973 at Bethlehem Coal Company's Fawn Mine near Saxonburg, PA. In attendance were personnel from the Bureau of Mines, MESA, Pennsylvania Department of Deep Mine Safety, Bethlehem Mines Corporation and MSA.

A preliminary demonstration of the vehicle's maneuverability was conducted to the group prior to entering the mine since we were limited in allowable test area to fresh air, once underground. The unit turned and traversed logs, as expected, with no problems.

The vehicle went underground at 11:21 a.m. with all systems operational, and came out at 1:35 p.m. for a total of two hours and 14 minutes of almost continuous operation.

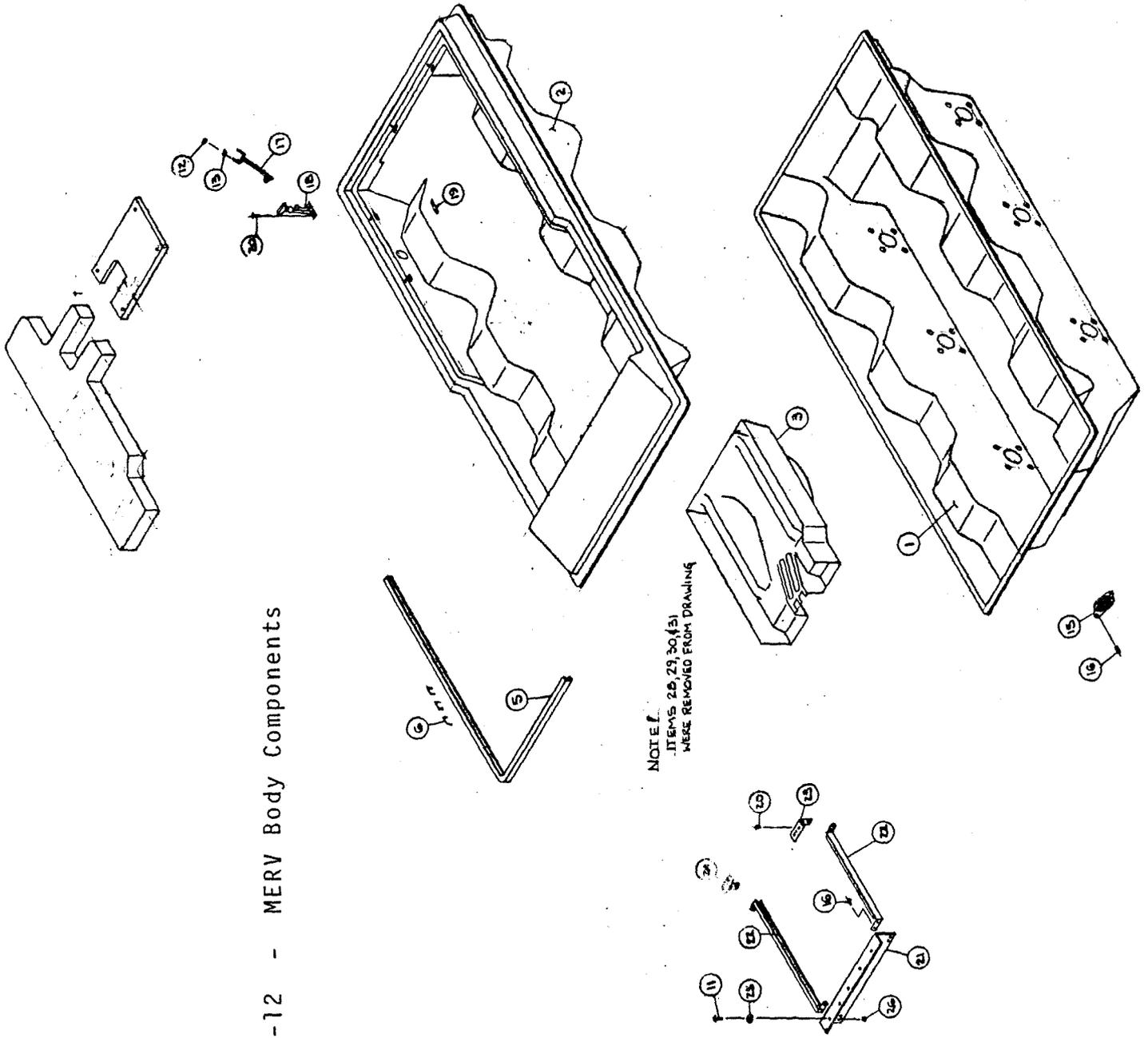


Figure 3-12 - MERV Body Components

TABLE 3-8 - KEY TO BODY COMPONENTS (FIGURE 3-12)

<u>Component Number</u>	<u>Description</u>	<u>Component Number</u>	<u>Description</u>
1	Lower Body	18	Top Latch
2	Upper Body	19	Back-up Plate
3	Floor Pan	20	3/16 Lg Flange Avex Rivet
4	Body Cover	21	Glide Channel Support Bracket
5	Rub Rail Molding	22	Glide Channel
6	Staples	23	Dash Panel Bracket (L.H.)
7	1/4 Turn Fasteners	24	Dash Panel Bracket (R.H.)
8	1/4 Turn Receptacles	25	1/4 Dia Fender Washer
9	Retainer	26	1/4-20 Wizlock Nut
10	Fire Extinguisher Mounting Bracket	27	3/16 Olympic Rivet
11	1/4-20 x 1 in. Hex Head Bolt		
12	1/4-20 Locknut		
13	1/4 SAE Flat Washer		
14	Fire Extinguisher	32	Top Cushion
15	Reflectors	33	1/4-20 x 1 1/4 Button Head Bolt
16	3/16 Avex Rivet		
17	Communication Retaining Strap		

During this period, the unit performed mechanically to expectations, maneuvering well, crossing track switches and muddy areas without hang-up and, in general, performing well. The total distance traveled was 2.8 miles while consuming only an apparent 40% battery charge.

On the day following the test, the battery was run to total exhaustion, covering an additional 5.8 miles in two hours and 27 minutes, for a total distance traveled of 8.6 miles over nearly a 5-hour period.

The following table shows the power requirements for the unit in conducting some typical operations. The trailer was attached, with either two or four riders, including the driver.

<u>Task Description</u>	<u>Reading (amps)</u>	
	<u>2 Riders</u>	<u>4 Riders</u>
1. Straight, level running	65-70	70-75
2. Up gentle slope (~ 12%)	110	130
3. Turning on level	150	150
4. Turning up gentle slope	175	180-190
5. Up steep slope	200	200

These readings were in the range expected for the vehicle and, with the in-mine and subsequent battery test, indicate that the basic drive-train mechanism and power is more than adequate for the prescribed mission time and performance requirements.

### 3.2 BATTERIES

The battery requirements for the MERV, as originally specified in the contract, were that the battery should be a rechargeable, 400 ampere-hour battery, with a minimum capability of 75 charge/discharge cycles and a minimum one-year life in the charged condition. A normal recharge time of 30 hours was stated, with a target recharge time of five hours. A replacement battery was to be provided.

The battery initially selected for the MERV was a silver-zinc 24-cell unit designated as an LR 290 by Yardney Electric Corporation. This battery met the general requirements set forth above and performed satisfactorily in the vehicle demonstrations. The total weight of 240 pounds and small volume made their selection almost mandatory to meet the overall vehicle weight and size specifications.

The LR 290's, however, would not meet the 75 charge/discharge cycle capability if defined as deep, or nearly complete discharges and, unless pulse charged, could not meet the 5-hour recharge target time. The recharge criterion, although not emphasized in the contract Scope of Work was obviously critical to the intended vehicle mission, and resulted ultimately in the vehicle being designed for a lead-acid replacement battery.

When the mission was redefined to a 4-hour period, the battery specifications were changed accordingly. A comparison of the 8-hour and 4-hour specifications are shown as follows:

	<u>8-hour Mission</u>	<u>4-hour Mission</u>
Capacity	400 AH	240 AH
Mission	8 hours	4 hours
	2 hours - full load and 6 hours - 1/2 load	2 hours - full load and 2 hours - 1/2 load
Voltage	36	36
Recharge time	8 hours (50 amps)	4 hours (60 amps)
Cycle life	Minimum of 75 charge/discharge cycles (80% discharge)	

As a part of the program, MSA conducted an evaluation of the battery requirements based on the shorter vehicle mission and surveyed the general battery field to provide a more suitable, less expensive battery than the LR 290's. Lead-acid was the preferred battery and all avenues were explored to employ it as the existing vehicle battery material.

Lead-acid battery suppliers contacted included the following:

C & D Batteries  
 Exide  
 Gould, Inc.  
 K & W  
 General Battery Corporation  
 Eagle-Picher Industries  
 Gates Energy Products, Inc.

In addition, such sources as NASA, General Energy Development, Atomics International and Yardney Electric were surveyed for general development on newer batteries such as nickel-cadmium, nickel-zinc, nickel oxide, silver-zinc, etc.

A summary of the characteristics of four possible replacement batteries is shown in Table 3-9. Silver-zinc and lead-acid batteries were commercially available, the silver-zinc battery being a larger, heavier-duty type than the LR 290. Nickel-zinc and iron-nickel batteries, on the other hand, appeared to be promising future candidates with high power densities, but were still in the development stage.

A weight and size penalty would have to be paid to employ a lead-acid battery. A comparison of the silver-zinc used in the original design with the proposed lead-acid battery is shown below.

	<u>Silver-zinc</u>	<u>Lead-acid</u>
Length	26 in.	26 in.
Width	17 in.	17 in.
Height	8 3/4 in.	16 in. (+ 7 1/4 in.)
Weight	240 lbs	520 lbs

Although the weight increase was significant, performance tests on the MERV with additional weight demonstrated it to be capable of operating without a performance penalty. Lead-acid, therefore, was chosen as the replacement battery.

TABLE 3-9

Summary of Batteries That Would Meet 4-hour MERV Mission Specifications

	<u>Silver-Zinc</u>	<u>Nickel-Zinc</u>	<u>Lead-Acid</u>	<u>Iron-Nickel</u>
Power Efficiency (watt hrs/lb.)	30-36	25-30	15-20	20-30
Projected Weight (lbs.) 240 AH battery	275	400	500	400
Cell Life	2 yrs.	2 yrs.	2-1/2 - 3-1/2 yrs.	3-4 yrs.
Present Status	Commercially available	100 AH batteries now under test. 350 AH batteries to go under test in 1975. Not available until late 1975.	20 watt hrs./lb. batteries have been built for 30 AH batteries. Batteries for our specs would be in 15-16 watt hrs./lb. efficiency.	Now under test at Westinghouse in vehicles. Would entertain design of battery for our unit.
Projected Costs (1975)	\$15,000 - highly dependent on silver price fluctuations.	In mass production, approximately the same as lead-acid.	1st set - \$22,000; each one thereafter at \$1000 each.	Not available.

This section discusses the design of the lead-acid batteries now used in the MERV units. Details on the silver-zinc batteries originally used, as well as study conducted by Ocean Energy Inc. on the possibility of pulse charging the original silver-zinc cells as a means of meeting the recharge specifications, are appended.

### 3.2.1 Cell Design

The lead-acid battery accepted for the MERV was based on six modules of three cells each from C & D Batteries, Plymouth Meeting, Pennsylvania. The battery is rated at 240 AH at the 4-hour rate to a final voltage of 1.75 v/c at 77°F. The capacity drops approximately 10% if operated at 50°F. Each cell weighs approximately 90 pounds.

Figure 3-13 shows the design of the individual module. The outside tray is polycarbonate, which has lifting lugs for easy replacement. The overall height of 17 3/4 inches includes the lifting lug and, along with the necessary clearance for the cover, dictated approximately a 1-inch increase in height for the vehicle.

The cells have an aircraft-type vent that will allow the battery to be tilted to a maximum angle of 110° without electrolyte leakage. If leakage should occur during suspension of the MERV unit below an elevator cage while being lowered down a mine shaft, the amount would not be significant over a half-hour period, long enough in more circumstances to make the descent.

### 3.2.2 Battery Design

The design of the battery, which includes the configuration of the cells and the protective case, had to take into account a number of factors including available space, temperature effects, convenience of replacement and maintenance, and weight. Ultimately, special permissibility permits had to be obtained on the battery terminals, wiring and case to achieve the desired end result.

#### 3.2.2.1 Configuration

The cell configuration in the battery, within limits, can be made to suit space available in the vehicle. Some important points considered, however, were as follows:

- Overheating causes premature cell failure. At least two sides of the cell should be exposed to the air for heat dissipation.

If clustering is necessary, air space should be provided between cells.

- The battery leads to the controller cannot be longer than 36 inches without additional fuzing.
- The battery design and placement within the vehicle should be convenient for easy replacement.

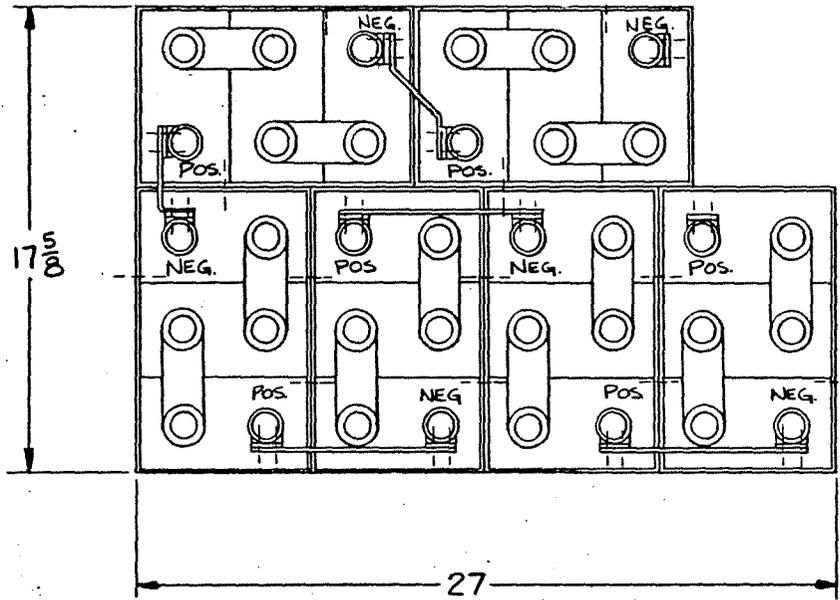
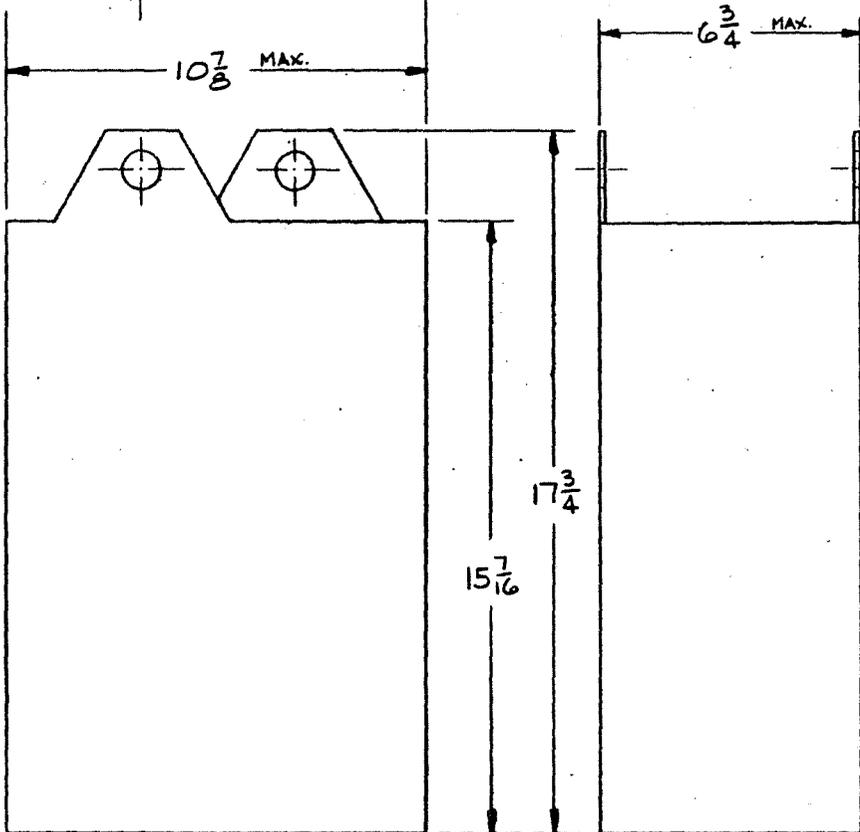
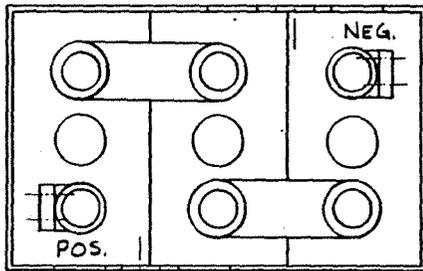
The final battery configuration consisted of the module arrangement shown in Figure 3-13. Each module is tied in series to the adjacent module with a double-bolted connector. This arrangement allows them to be disconnected and results in a maximum lift of 90 pounds for replacing the battery. This should be reasonable for two men either in confined space or in the open.

The charger automatically starts delivering current at 20 amperes/100 ampere-hours of rated capacity. This means a full-rated charge is delivered to the battery during the 8-hour recharge period -- especially important when the battery is occasionally discharged beyond the recommended level. Typically, an ER charger will return 90% of rated capacity in six hours and 105% or more in eight hours.

The battery's counter voltage buildup controls the charge rate for a smooth tapering recharge characteristic. Charge current tapers rapidly as the battery gassing voltage is reached -- in about six hours for normal recharge to a low end-of-charge value (approximately 3 amps/100 amp hours of rated capacity, increasing with battery age). This minimizes water consumption and reduced the need to add water. The low finish current is maintained for an additional three hours during the periodic equalize-charge cycle.

Permission was obtained from the Bureau's Approval and Testing Branch for the use of double-bolted connectors, rather than soldered inter-module battery terminals for ease in battery replacement in the mine. Insulation covered both the terminals and the connector. Special terminals were designed for connecting the charger without having to disconnect the power leads to the controller. A picture of the battery in place in MERV-1 is shown in Figure 3-14.

Permission was also obtained for the elimination of a running plug between the battery and the controller as a safety feature on the MERV. The controller wiring features a manual reset relay which accomplishes the same purpose.



PLAN VIEW OF 6 BATTERY ASSEMBLY

SINGLE BATTERY  
IN CASE

REF: C&D DRAWING No. M-6547-2

Figure 3-13 - Lead-Acid Cell and Battery Design

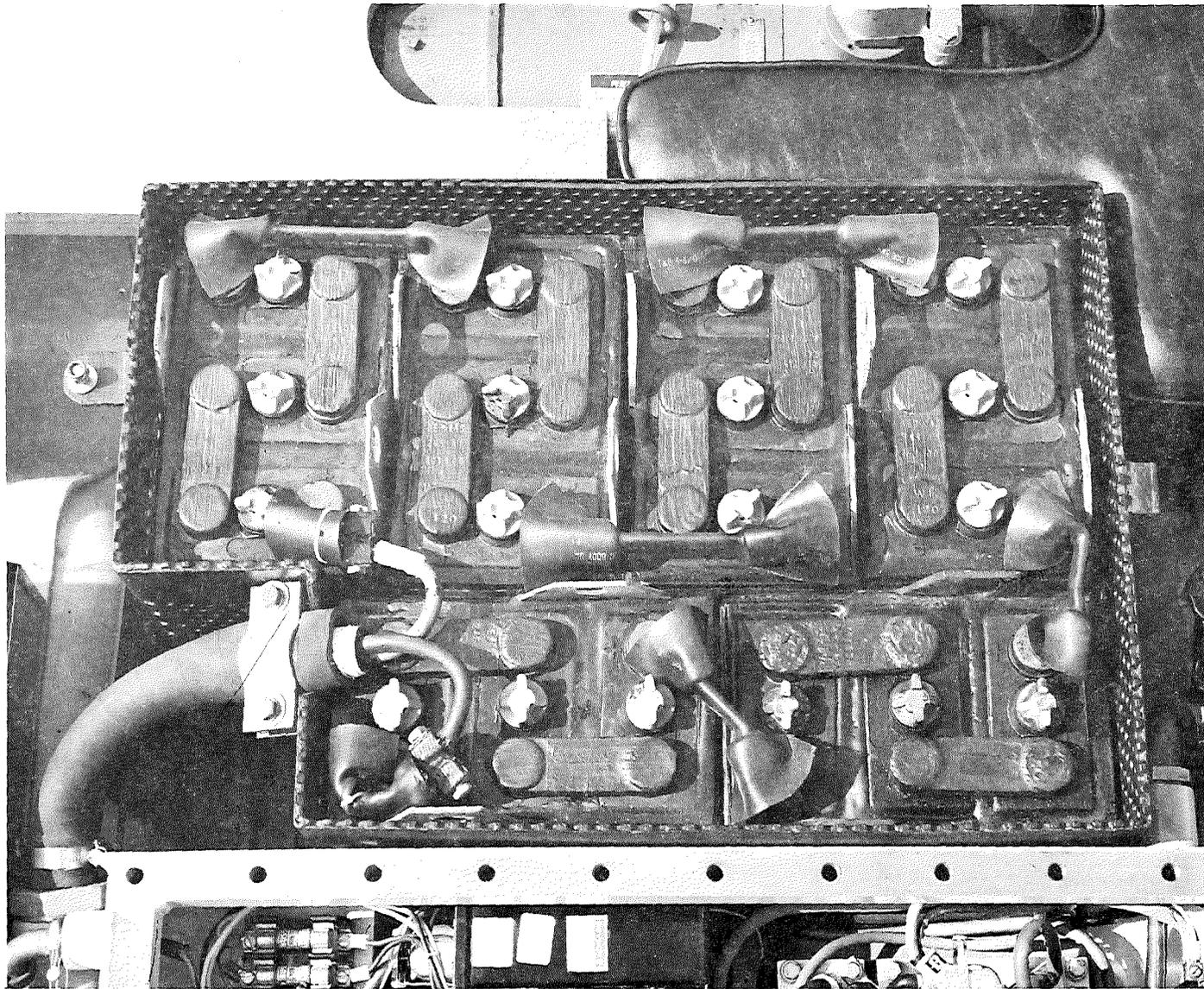


Figure 3-14 - View of Lead-Acid Battery

### 3.2.2.2 Battery Case

Figures 3-15 and 3-16 show the design of the battery case and cover as fabricated for the vehicle. The battery case base is constructed of perforated 3/16 inch thick steel with 50 percent void space for weight savings. A fire-and-acid resistant plastic coating was provided for corrosion resistance. The battery-case top is fabricated from solid 3/16 inch thick steel sheeting, coated inside and out with the same plastic material.

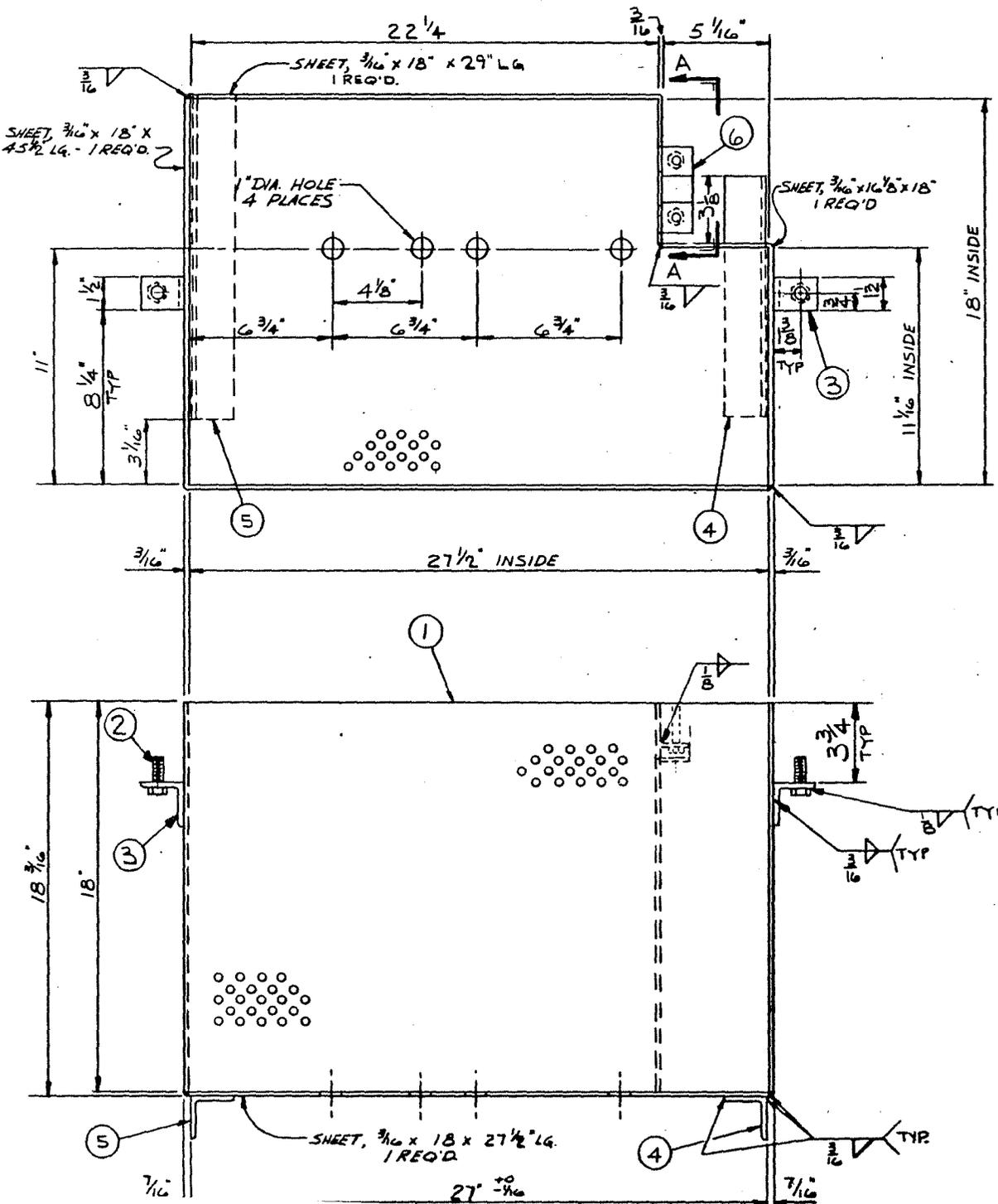
### 3.2.3 Charger Specifications

The charger provided for the lead-acid batteries is C & D's commercial charger ER18Cell5G, an 18 cell, ferro-resonant-regulated charger. It is fully automatic, has a built in current limit and, if a problem arises, is fail-safe to protect the battery.

### 3.2.4 Battery Status Indicator

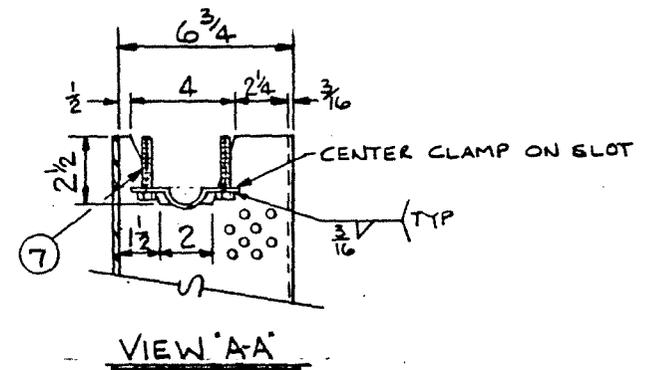
The battery status indicator is a Model 933 unit manufactured by Curtis Instruments, Inc., Mt. Kisco, New York. The indicator monitors the terminal voltage of the battery, a function of battery e.m.f. and voltage drop across the internal resistance, and integrates current withdrawn as a function of time. It depends, for accuracy, on knowing the discharge characteristics of the specific lead-acid battery to determine the current being withdrawn as a function of the terminal voltage. The end result is a readout of the charge status of the battery displayed on a "fuel" gage mounted on the MERV dash.

The Model 933 has an automatic reset capability. Upon connection to a fully-charged battery (90% to full) the gauge will reset to the charge status of the new battery.



PARTS LIST			
ITEM NO.	PT. NO. DWG. NO.	REQ'D.	DESCRIPTION
1			SHEET, 3/16" PERFORATED, H.P. STEEL, .328" DIA. STAGGERED HOLES, 7/16" CENTERS, 50% OPEN AREA
2	57626	2	SCREW, CAP, HEX, HQ, 3/8-16 x 1 1/2 LG
3	20209	2	ANGLE, 2" x 2" x 1/4" x 1 1/2" LG
4	20209	1	ANGLE, 2" x 2" x 1/4" x 11 1/4" LG
5	20209	1	ANGLE, 2" x 2" x 1/4" x 15 1/8" LG
* 6	D44705	2	CLAMP, STRAIN
7	63160	2	SCREW, CAP, HEX, HD, 3/8-16 x 2" LG

\* FURNISHED BY MSA, ONLY 1 SHOWN

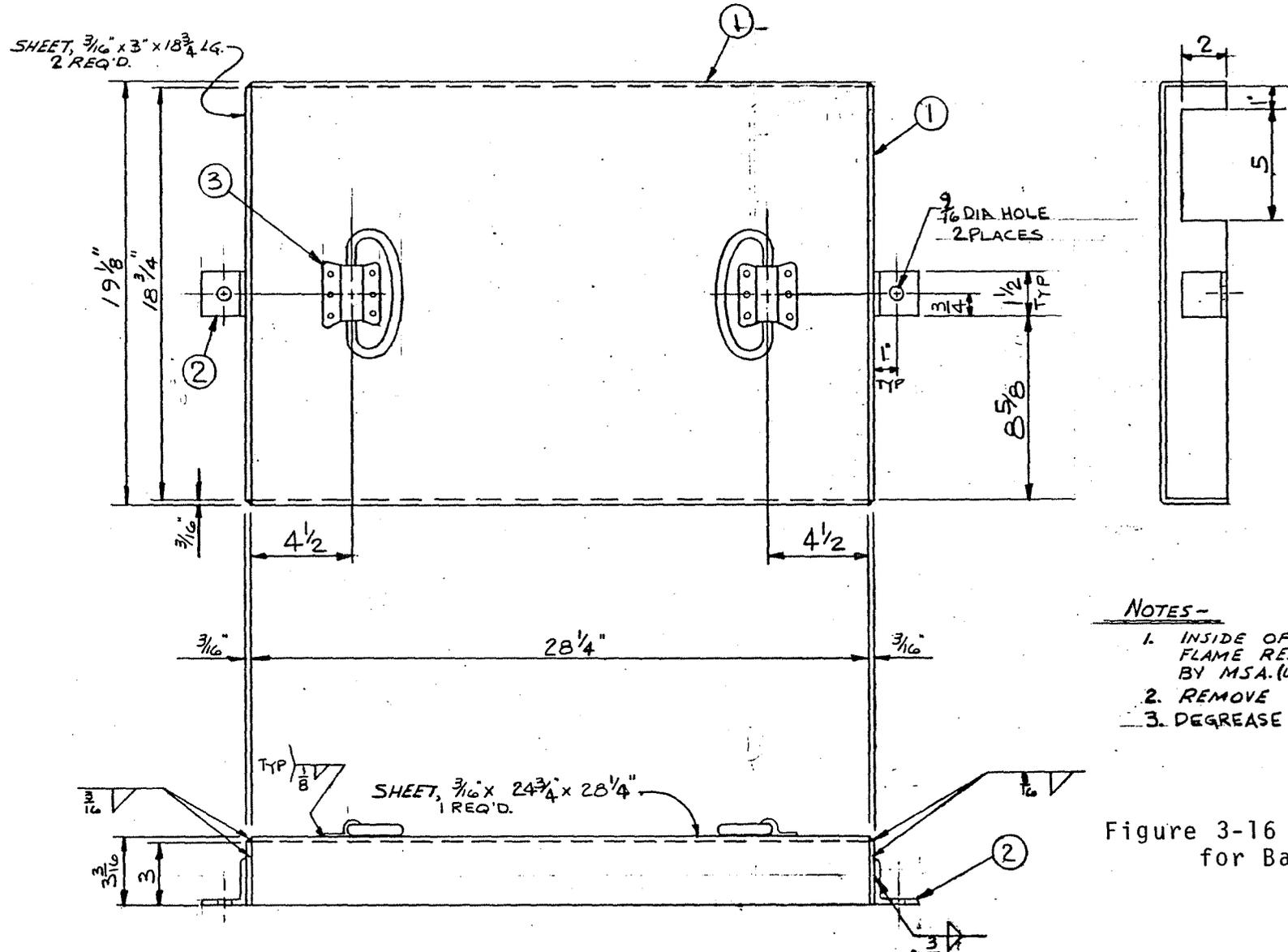


CPR-266-411

NOTE!  
1. DEGREASE BOX. DO NOT PAINT.

Figure 3-15 - Design of Battery Case

PARTS LIST			
ITEM NO.	PT. NO. DWG. NO.	REQ'D.	DESCRIPTION
1			SHEET, 3/16" THK. H.R. STEEL
2	20209	2	ANGLE 2x2x1/4x1 1/2 LG.
3		2	HANDLE, SUITCASE, STEEL



CPR-266-412

NOTES-

1. INSIDE OF COVER TO HAVE 1/8" THK. FLAME RESISTANT SHEET SUPPLIED BY MSA. (USE N-350 NEOPRENE-GATES Eng. Co.)
2. REMOVE ALL WELD SPLATTER.
3. DEGREASE COVER. DO NOT PAINT.

Figure 3-16 - Design of Cover for Battery Case

### 3.3 INSTRUMENTATION

The MERV is equipped with instrumentation to monitor the following: Methane concentration from 0 to 5 percent; oxygen concentration from 0 to 25 percent; and carbon monoxide concentration from 0 to 5000 ppm. The instrument module, a front view of which is shown in Figure 2-4, is a self-contained package complete with batteries for power, which can be slid out for accessibility to the components, or easily removed for replacement, storage in a laboratory environment, or calibration. A spare module has been provided.

The instruments have individual alarm lights and a common, large blinking alarm light prominent on the control panel. Alarm conditions can be selectively acknowledged to "quiet" the common alarm.

The alarm system also features a tie-in to the communications system, providing a coded tonal alarm heard by both the operators and the base station. A "normal" tone signal is repeated at a preselected repetition rate. This tone is an indicator of the functionality of the system.

Three successive time slots are allocated immediately following each normal tone: one for a low tone, one for a medium tone, and one for a high tone. Each slot is assigned an associated alarm. Thus, the status of alarms may be audibly decoded by persons monitoring the telephone line independently of other communications.

In addition to the permanent instrument console, portable instruments for monitoring of methane and oxygen during extra vehicular activity and standard MSA colorimetric indicator tubes for hydrogen sulfide and nitrogen oxides are also provided.

#### 3.3.1 General Design Considerations

The instrument package has gone through several modifications to evolve into the present form. The initial specifications called for monitoring the methane concentration from 0 to 5 percent, oxygen concentration from 0 to 25 percent, carbon monoxide concentration from 0 to 500 ppm, and the carbon dioxide concentration from 0 to 10 percent. To accomplish this, a package consisting of standard methane and oxygen monitors, our hopcalite-based CO sensor, and a two-thermister thermal conductivity-based CO<sub>2</sub> sensor was assembled. Except for the CO<sub>2</sub> monitor, all the monitors had been previously designed by MSA (in one form or another) to be used underground. The primary accuracy of the system depended on an accurate

measure of flow rate of sample delivered. Power was supplied from the main propulsion battery, from a voltage regulator located in the controller housing.

From the outset, problems were encountered with the alarm circuitry. When the MERV was operating, electrical noise from the propulsion battery and speed control assembly frequently triggered alarm responses. Relief was effected by incorporating time delays into the alarm circuits, thus requiring that an alarm condition persist before it would be acknowledged. But some electrical noise problems remained, however, and it became evident that the power supply for the instruments would have to be divorced from propulsion circuitry.

In addition to the spurious alarms, inaccurate readings were observed during the various tests. In a subsequent evaluation of the instrument package, the problems were considered to be twofold: (1) Accurate and precise flow rates of sample through the package could not be maintained; and (2) the thermal conductivity-type CO<sub>2</sub> sensor suffered seriously from cross-sensitivity, with H<sub>2</sub>O, Ar, O<sub>2</sub> and N<sub>2</sub> all showing an effect.

With these three shortcomings of the package -- namely motor-induced electrical noise interferences; drifts due to variations in sample flow rates; and cross-sensitivity of the CO<sub>2</sub> sensor -- the decision was made to do a major revision on the package, with the following changes considered paramount:

- Provide the package as a self-contained, easily replaceable unit.
- Provide a separate battery power supply, completely isolated from the main propulsion system. This battery supply would provide power for the flow system pump, transducer bridges, analog circuits, and digital circuitry.
- Eliminate the CO<sub>2</sub> sensor.
- Substitute an electrochemical-type cell for CO detection in place of the hopcalite unit previously in use.
- Make all sensor heads the diffusion type.

The substitution of the electrochemical cell for the CO sensor in place of the hopcalite-based unit was made to minimize some design problems and to obtain an instrument that would monitor CO in the 0-5000 ppm range desired by MESA. A comparison of the cells is shown in Table 3-10.

TABLE 3-10 - COMPARISON OF ELECTROCHEMICAL AND HOPCALITE-BASED CO SENSORS

<u>Parameter</u>	<u>Electrochemical</u>	<u>Hopcalite</u>	<u>Advantages of Electrochemical</u>
1. Sensor Type	Fuel Cell	Detector in Wheatstone Bridge	Reduced power consumption
2. Water Sensitivity	None	Must be heated and/or dried	
3. Cell Heaters	Not required	Needed for hopcalite	Reduced power consumption
4. Driers	Not required	Useful for sample conditioning	Reduced maintenance
5. Service Life	Predictable	A function of adequacy of sample preparation	
6. Flow System	Low head and flow (Diffusion-type)	Relatively high head and flow	Increased pump life; reduced power consumption
7. Range	0-500 (avail) 0-5000 (approx.)	(0-500 ppm if all the above done)	

There was obviously a considerable advantage to the use of the electrochemical cell for the monitoring system in place of the hopcalite unit previously used.

With the changes listed, the following improvements were anticipated:

1. Stand-alone operation of the instrument tray.
2. Gas flow rates no longer critical. Pump provides sample flow to diffusion-type rather than flow-through-type sensors.

3. Elimination of instrument tray/controller housing wiring.
4. Elimination of power supplies from the controller housing.
5. Simplification of approval for intrinsic safety.
6. Simplification of, and elimination of the need for, ancillary equipment to do bench testing.
7. Reduction of field service. A spare tray could be readily interchanged.

In addition to the above, the decision was made to increase the CO range to 0-5000 ppm and to include the communications as an integral part of the instrument-tray package, with an independent power supply, but interfaced with the alarm circuitry of the gas-monitoring equipment to provide audible alarm signals in addition to the visual alarm lights.

### 3.3.2 General Arrangement and Operation

The instrument package, as finally developed, is a self-contained system mounted on a tray that inserts in a slot provided at the front of the vehicle in full view of the operator and his assistant. The instrumentation components and batteries are completely contained in the tray, a top view of which is shown in Figure 3-17, along with the communications circuit boards and battery supply. This latter simplifies the interfacing of the communications with the alarm circuitry and makes the entire instrument operating assembly transportable for calibration or storage in a laboratory-type environment, or for rapid in-field replacement.

In operation, the gas sample is drawn into the flow system by the sample pump from a 36-inch-long external metal probe (not shown) and a 15-foot section of flexible sample line. The probe/flexible-line combination allows the operator to sample gas ahead of the vehicle or at locations overhead or otherwise inaccessible to the operators. In the module, the gas first passes through a filter and the pump, and then passes the three instrument sensors in order: carbon monoxide, oxygen and methane. After passing the methane sensor, the sample is exhausted through a flow meter to indicate to the operator the availability of suitable gas volume.

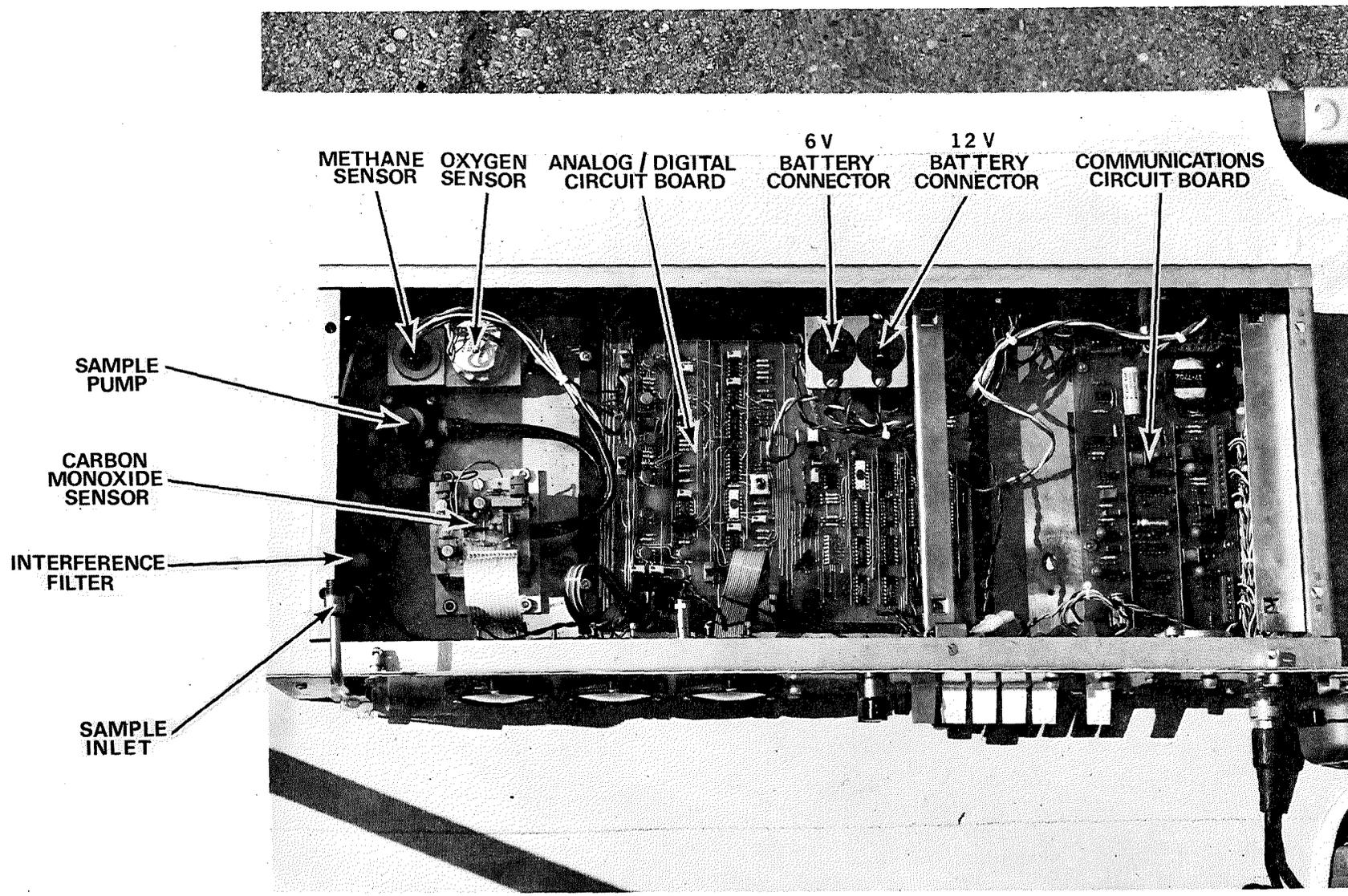


Figure 3-17 - Top View of Instrument Tray

A front view of the panelboard is shown in Figure 3-18. The functions, shown left to right, are the sample flow meter calibrated for a range of 0-10 SCFM, the three gas-monitoring meters and individual alarms, the common alarm light and acknowledge button, and power switches.

The instrument power switch controls all instrument power. The LED above the switch indicates instrument battery status (red = low; green = normal). The individual instrument switches, when turned OFF, disable the instruments and alarm interfaces. The pump switch deactivates the pump for stand-by operation.

### 3.3.3 Circuitry and Power Supplies

A schematic of the instrument module showing some of the interfacing and control circuitry is shown in Figure 3-19.

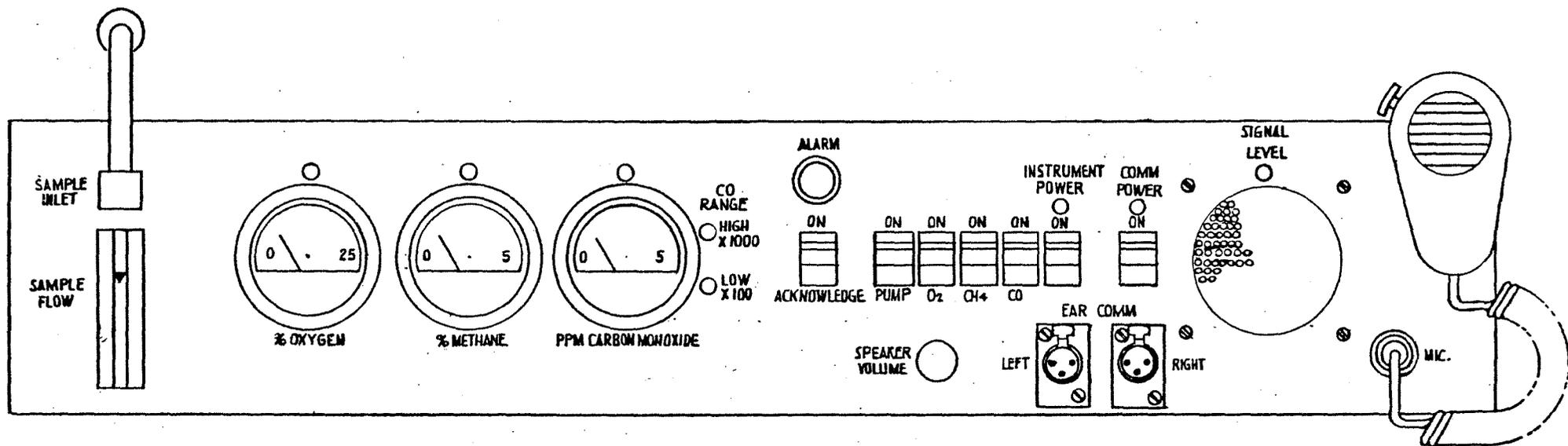
The entire instrument system is powered by a 6 volt (five NiCd cells) battery. The cells are current-limited by resistors, and further protected by a circuit breaker. Interconnects allow the batteries to be charged in the instrument panel, or separately as spares. Regulators derive the necessary voltages from the battery pack for the gas sensors, instrument amplifier circuits, sensor alarm comparators, and the low battery comparator.

### 3.3.4 Oxygen Sensor

The oxygen sensor is the galvanic cell used in the MSA Model 244 Oxygen Indicator. Since the redox reactions involved in cells of this type consume chemicals, the cell life is finite and should be replaced approximately every six months.

The schematic of the circuitry is shown in Figure 3-20. The sensor generates a voltage that is proportional to the oxygen content of the air sample. Its output is connected to the analog/digital board where it is amplified to drive the panel meter and alarm comparator. The alarm comparator triggers on the downscale oxygen level (oxygen deficiency) to yield a positive level alarm signal. The signal is interfaced with the communications system to provide a tonal alert.

Provisions for circuit-check calibration and adjusting the alarm point are available and easily accessible. The alarm point is adjustable and generally set to activate below 18% oxygen.



CSK-3026-74

Figure 3-18 - Front Panel of Self-contained Instrument/  
Communication Module

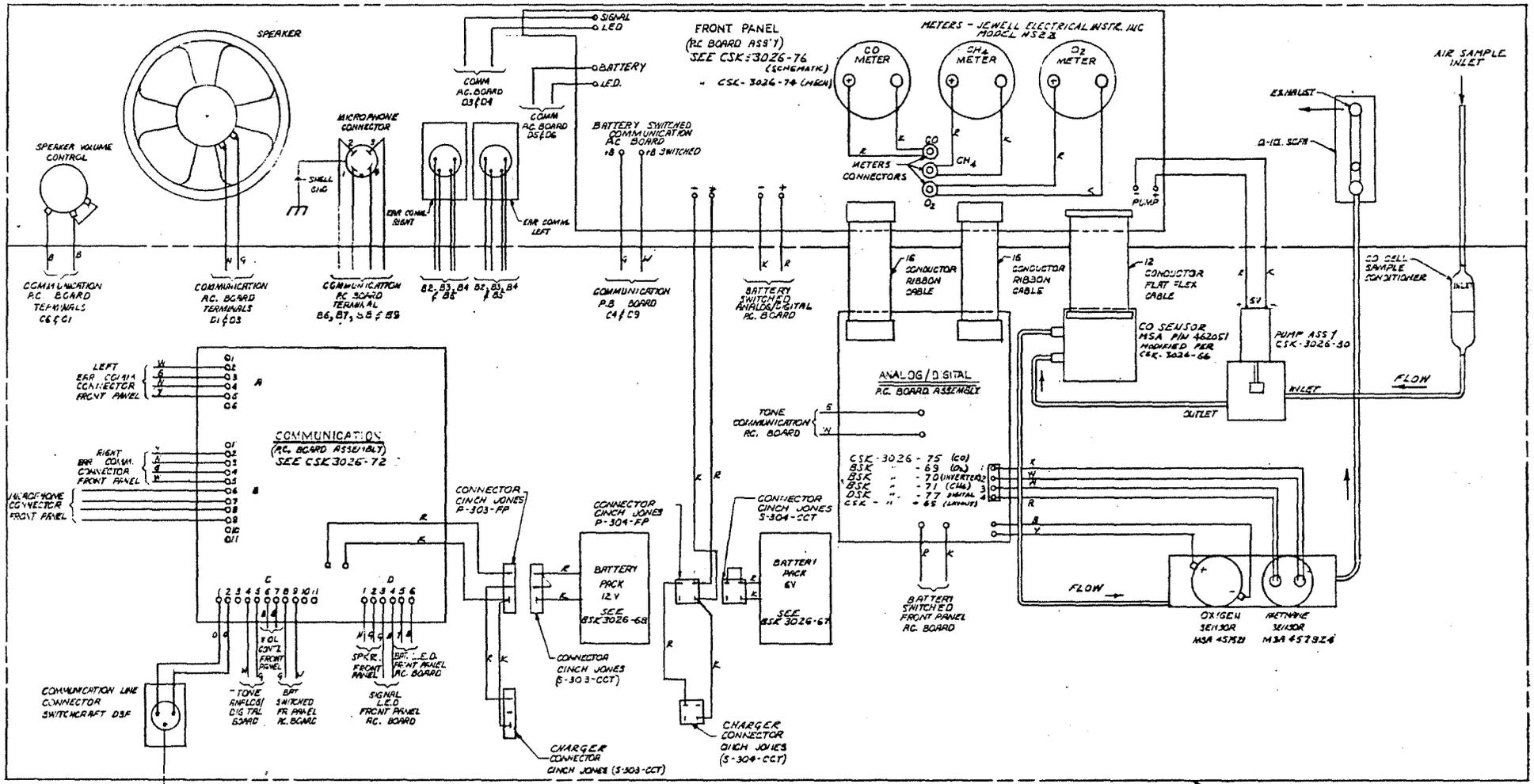
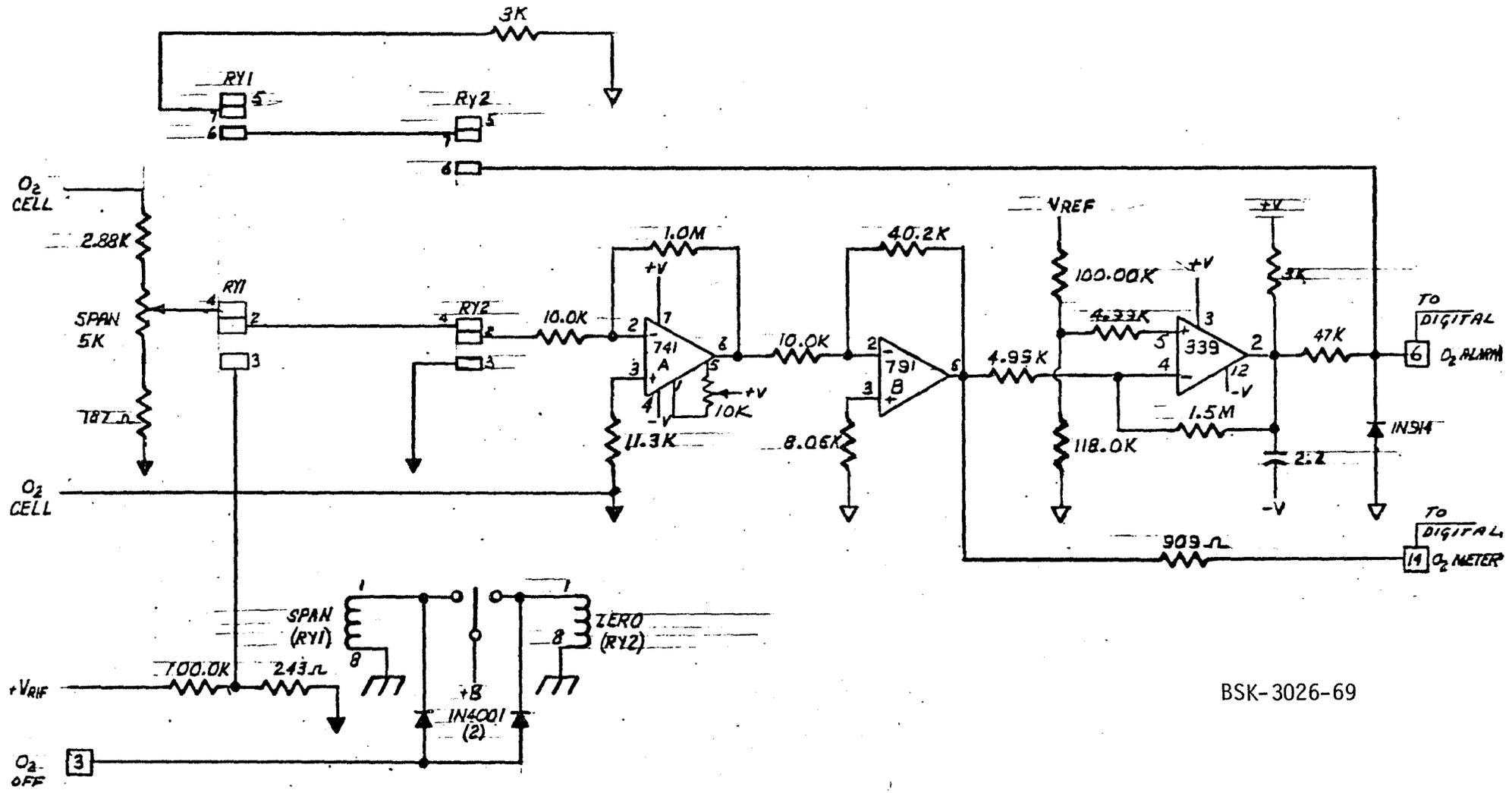


Figure 3-19 - Schematic of Instrument/Communication Circuitry

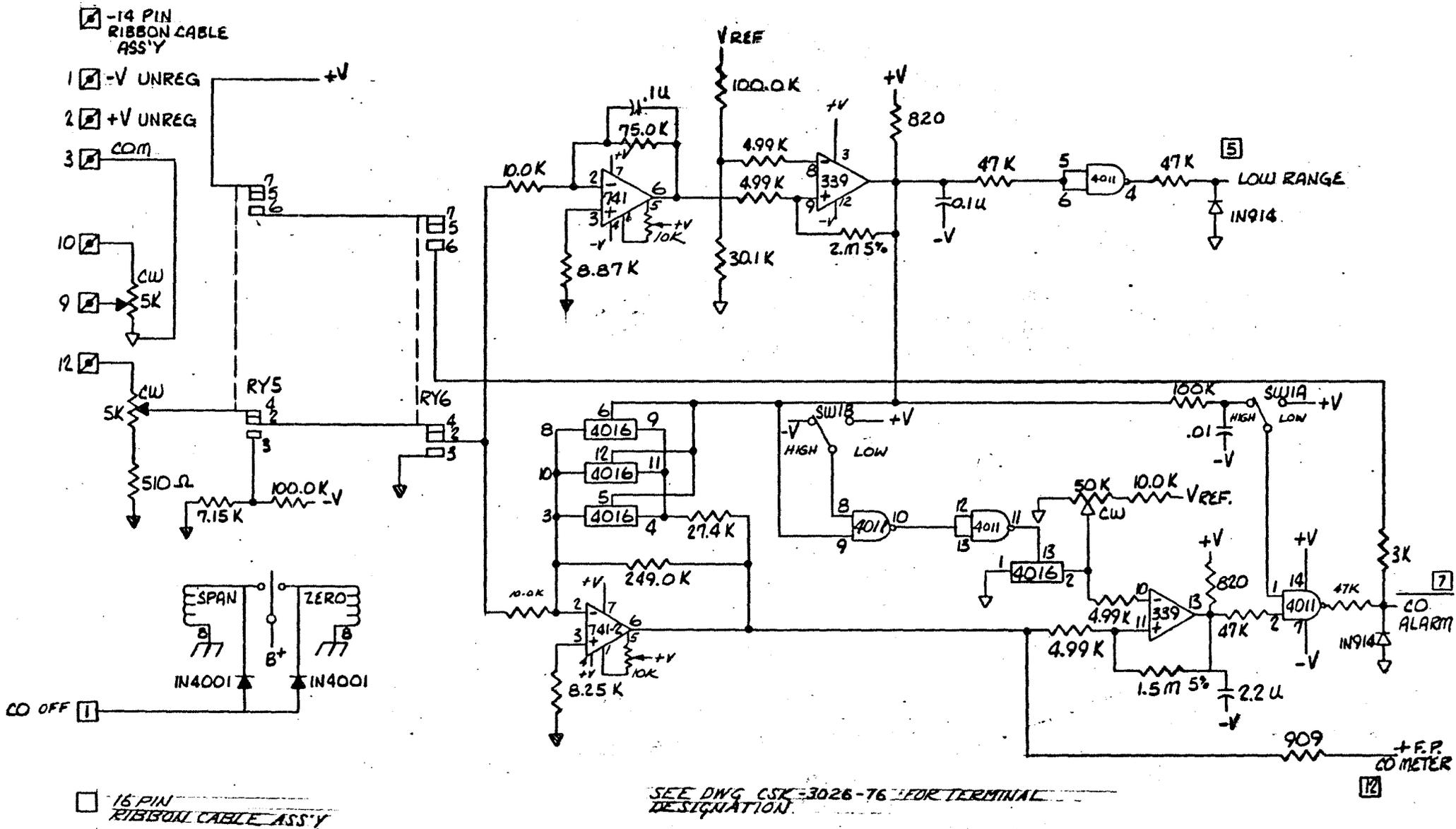
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BSK-3026-69

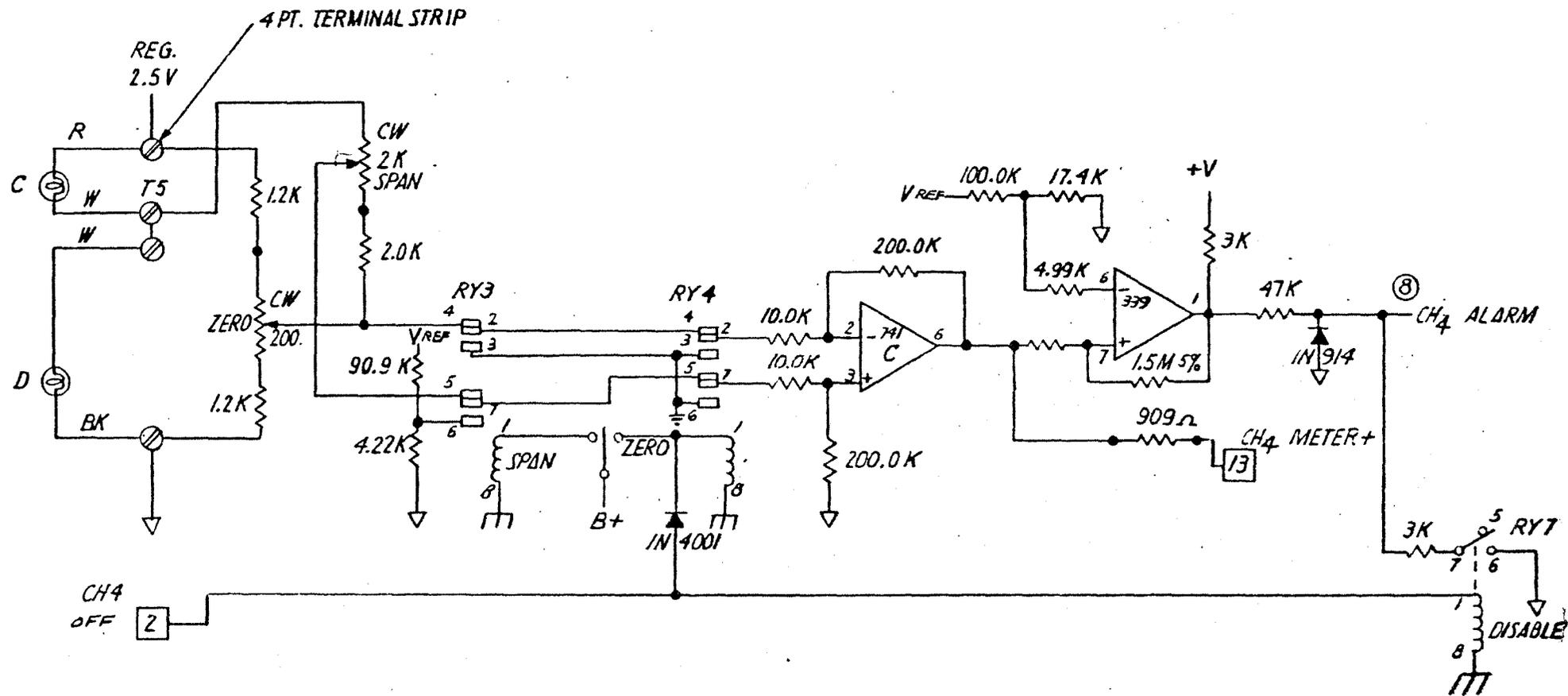
□ 16 PIN RIBBON CABLE ASS'Y.

Figure 3-20 - Schematic of the Oxygen Sensor



CSK-3026-75

Figure 3-21 - Schematic of the CO Sensor



□ 16 PIN RIBBON CABLE ASSY

BSK-3026-71

Figure 3-22 - Schematic of the Methane Sensor

### 3.3.5 Carbon Monoxide Monitor

The CO sensor is the electrochemical type presently used in MSA's Model 70 CO indicators, but modified to give the dual ranges of 0-500 and 0-5000 ppm CO concentration. A sample introduced into the sensor cell by the flow system diffuses into the cell through a Teflon membrane. The cell has no consumable electrodes and is therefore self-sustaining.

The schematic of the CO sensor is shown in Figure 3-21. The basic working range is 0-500 ppm. Should the concentration exceed 450 ppm, an automatic range change occurs. The range change is effected by lowering the feedback resistance of the meter amplifier (Component 741-2) upon approaching full scale, by the use of three parallel transmission gates. The range change is automatically reversed on descending CO concentration.

The output of the meter amplifier drives the panel meter and comparator circuits. The comparator triggers on an upscale voltage reading corresponding to an increase in CO concentration and the alarm signal triggers the individual alarm, general alarm light and audible alarm in the communication circuit.

The instrument tray has provision for checking the circuit, calibration and alarm-point selection and adjustment. The alarm can be set to trigger in either the LOW or HIGH range. It is presently set on the LOW range at approximately 450 ppm. Pressing the ACKNOWLEDGE button deactivates the general alarm light, but the individual alarm light remains ON.

### 3.3.6 Methane Monitor

The methane sensor is a combustible gas diffusion type used in both the MSA Methane Spotter and Model VI Methane Monitor.

A schematic of the sensor is shown in Figure 3-22. The output of the detector bridge is amplified to drive the panel meter and alarm comparator. The comparator triggers on an upscale voltage reading corresponding to an increase in methane concentration. The alarm signal triggers the individual alarm circuit, general alarm light and audible alarm in the communication circuit. Pressing the ACKNOWLEDGE button deactivates the general alarm light, with the individual alarm remaining ON.

The instrument tray has provisions for checking the circuit, calibration and alarm point adjustment. The alarm is presently set at a 2% methane concentration.

### 3.3.7 Audible Alarm System

The audible alarm system of the gas monitoring instrumentation package is a sophisticated feature which provides the following safety functions for the operators in the performance of a mission:

- a nonvisual alert of hazardous gas concentration to the operators.
- an alert to the base station of the hazardous conditions, as well as a continuous monitoring of general air conditions.
- a means of monitoring, by the base station, of the continuity of the communications payout wire.

The system is an integral part of the instrument package, receiving its signal from the alarm circuitry and its power from the instrument batteries. The circuitry is located in the instrument tray and the tie-in with the communication system is illustrated in Figure 3-19 (Section 3.3.3).

In operation, when there are no alarms, the system generates a NORMAL or "all clear" tone. This tone (approximately 1 KHz) is patched into the communications system at approximately four second intervals. The tone persists for approximately 0.25 seconds and is similar to the recurring tone which is present when a phone conversation is being recorded. The tone volume level is adjustable.

The tone "signal" does not signify that the sensor systems are operating properly, but rather that no alarm signal is being received. At the base station, however, the absence of the periodic NORMAL tone indicates a malfunction of the communication system. The NORMAL tone also serves as an audible reference to simplify decoding of an alarm condition.

Each of the vehicle monitoring instruments is assigned a tone frequency and time slot following the periodic NORMAL tone signal. The time slots follow the NORMAL signal and each other by 0.25 seconds and are 0.75 seconds long. They are assigned the following order and tone frequency.

1. Oxygen - low tone
2. Methane - medium tone, same as NORMAL
3. Carbon monoxide - high tone

If an alarm condition occurs with the oxygen instrument, a low frequency tone burst will be appended to the NORMAL tone 0.25 seconds after the NORMAL tone ceases. Should the methane instrument alarm also, a medium tone will follow the oxygen tone 0.25 seconds later. Under similar conditions, the high carbon monoxide tone would be appended. Thus, a three-alarm "word" is synthesized which will remain as a background-type signal that can be audibly decoded by persons monitoring the transmission line independent of other communications.

In the event that only a carbon monoxide alarm occurs, the tone alarm will be spaced at its assigned time period, not preceded by the oxygen and methane alarm tones. Similarly, a methane alarm will produce only a tone for methane in its assigned time period after the NORMAL tone.

The NORMAL tone is set at a user-definable volume which is anticipated to be audible but at background level. When an alarm occurs, the volume automatically increases to a higher, but not injurious, volume. This level may be reduced to the background level by actuating the ACKNOWLEDGE switch instrument on the panel, but the alarm "word" will repeat at the assigned interval until the alarm condition is no longer present, at which time the system automatically reverts to the NORMAL. This feature obviates the need for a reset switch. Any subsequent alarm, after the ACKNOWLEDGE button has been pressed, will revert the tones to maximum volume.

### 3.3.8 Portable Gas Sampling Equipment

Portable gas sampling equipment has been provided for sampling areas remote from the vehicle. MSA's Spotter Methane Detector and Model 244 Oxygen Indicator have been provided for checking the methane and oxygen concentrations, respectively. Both are hand-held, battery-operated instruments with display meters. The Spotter detects methane in the range of 0 to 5 percent in air. The Oxygen Indicator measures oxygen concentration over the range of 0 to 25 percent.

Detector tubes and a Universal Tester have been provided for spot checking for concentrations of hydrogen sulfide, nitrogen dioxide and nitric oxide. The tubes contain impregnated chemical that changes color when exposed to air containing the gas in question. The Universal Tester is used to draw a known volume of gas through the detector tubes and the concentration of the gas in the sample is read by the length of stain in the tube.

### 3.3.9 Temperature Indicator

The temperature monitor is a Weston bimetal two-inch stem-dial thermometer, mounted on the right-hand side of the instrument console. The model chosen has a liquid fill in the stem to dampen vibration effects.

## 3.4 COMMUNICATION SYSTEM

The contract requires two-way voice communication between the vehicle and a fresh air base for a minimum distance of 10,000 feet, with intercommunication between the two crew members. This has been provided, as well as the interfacing with the instrument alarm system described earlier (Section 3.3).

The basic communication system components are shown in Figure 3-23. The primary vehicle-to-fresh-air-base link-up is an intercom system consisting of the Base Station Unit and a similar unit mounted on the instrument module coupled through a two-wire link. The Ear-Com units, manufactured by Lear Sigler, provide intercommunication between crew members and the base station through ear-insertion speaker/mikes.

A wire payout system (not shown), adaptable either to the vehicle or the trailer unit, is capable of laying a trailing wire the required 10,000 feet. Alternate locations are provided for the payout canister; one in the vehicle, and a second on the trailer to avoid wire breakage when the trailer is in use.

A schematic of the communication system, with its tie-in to the instrument module and instrumentation alarm circuit, was shown in Figure 3-19 (Section 3.3). The wiring schematic for this system is shown in Figure 3-24.

### 3.4.1 General Design Considerations

Reliable two-way voice communication between the vehicle and its fresh air base is essential to successful operation of the vehicle during a rescue mission. To the extent that voice-communication capability increases the efficiency of utilization of the basic features of the vehicle, there is a trade-off in allocation of the resources available on the vehicle. The speed of reaction of either the rescue team or the base-station personnel to a change of conditions is greatly enhanced by the voice communication system. Timely appropriate reaction permits completion of a successful rescue mission within the range limitation of the vehicle in a

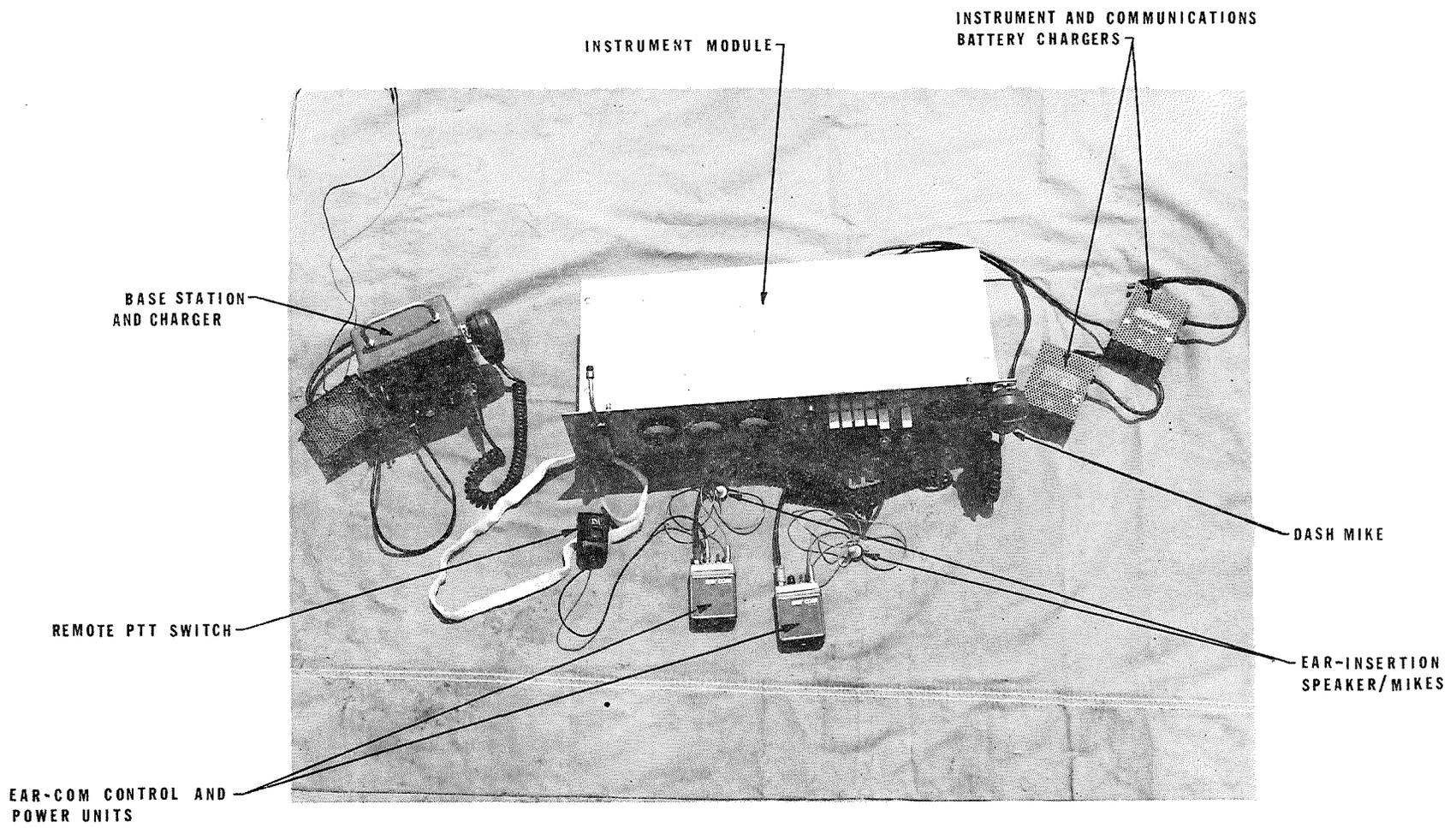
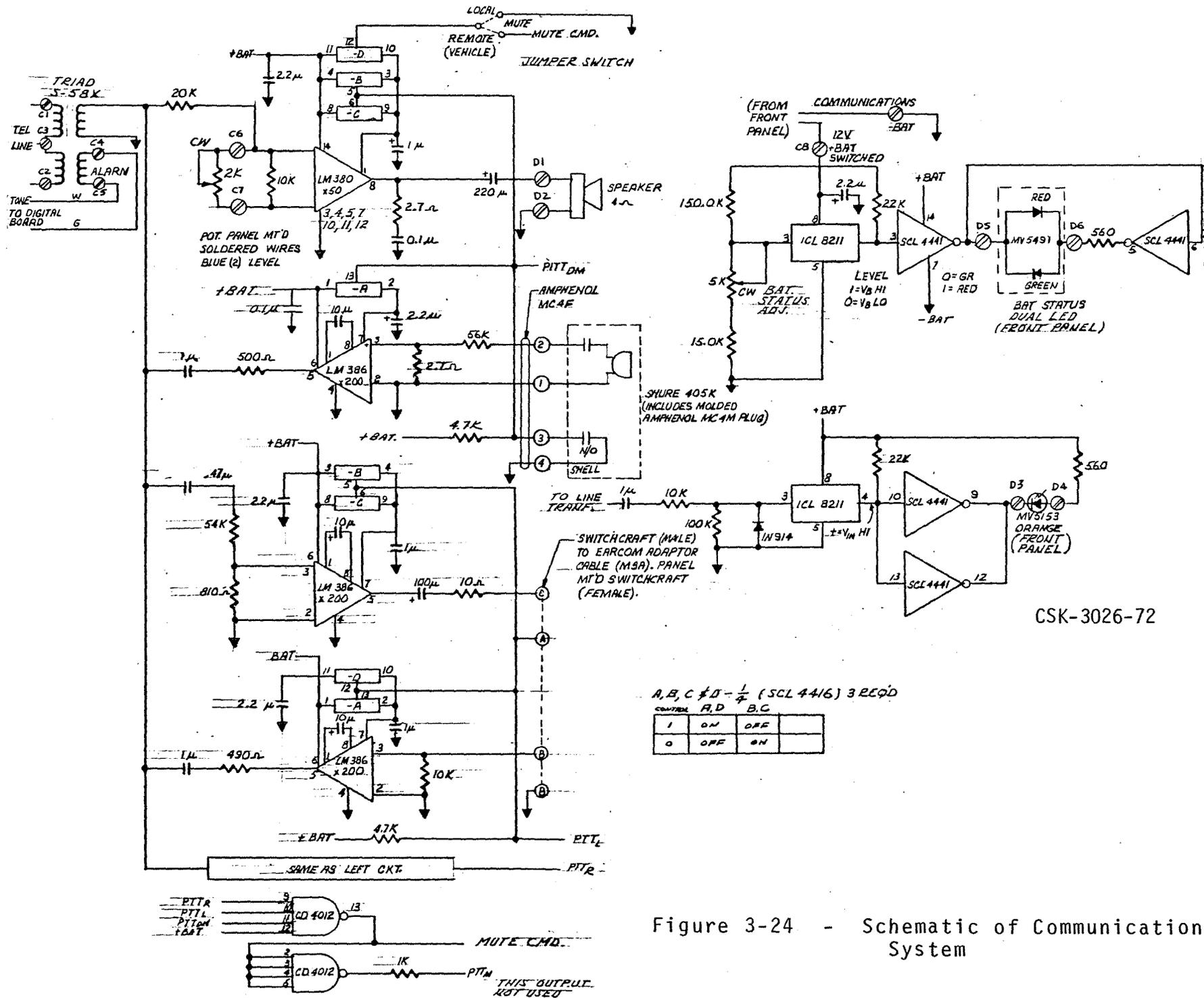


Figure 3-23 - Communication System Components



CSK-3026-72

A, B, C ≠ D - 1/2 (SCL 4416) 3 REQ'D

CONTROL	A, D	B, C
1	ON	OFF
0	OFF	ON

Figure 3-24 - Schematic of Communication System

situation which otherwise, for safety reasons, would require the establishment of another fresh air base.

The major problem in the communication system design involved obtaining the required high degree of reliability within the allocatable resources of the vehicle; i.e., within the size, weight and power limitations. The importance of the rescue vehicle's mission justified an interference-free communication link. This link was best provided as an intercom system using an expendable wire as the means of communication. The system design was closely tailored to the characteristics of the wire used in the link as well as the talking range required.

Wire size was a major consideration. Extremely light-gauge wire is available to minimize weight and storage volume, but a somewhat heavier U. S. Army Signal Corps field telephone wire was selected for better reliability.

Convenience was also a major consideration. Crew members are expected to be under stress and busy with the operation of the vehicle and making observations. Controls, therefore, had to be at a minimum, and operable without undue problems.

#### 3.4.2 Description of System

The major system components can be subdivided into the following:

- Vehicle to fresh air base intercom system
- Expendable wire link
- Crew intercommunication system

##### 3.4.2.1 Vehicle to Fresh Air Base Intercom System

The Base Station and Vehicle Dash Intercom units are the basic components for primary vehicle-to-base communications. Both are basically similar, with a speaker, amplifier, and push-to-talk (PTT) microphones and are powered independently with rechargeable 12-volt NiCd batteries.

The base station unit has an internal speaker with an attached PTT microphone. The wiring is effected by means of a printed circuit board, thus simplifying electrical connections. A schematic of the wiring is shown in Figure 3-25. Other features include:



- Red/green LED battery - level monitor
- Line monitor LED that responds with the nominal AC signal level on the line. This indicator performs a self-test function to give system performance checks.

The Vehicle Dash unit is electrically the same as the Base Station, but its power is derived from the tray-mounted 12 volt supply. One of the two tray-mounted communication printed circuit boards, therefore, is the same as that used in the base station. A red/green LED battery level monitor is panel-mounted.

The speaker is panel-mounted with an associated volume control. The PTT mike is also dash-mounted, and accessible to both crew members.

Unless PTT actuated, both units are in the "listen" mode, with the transmit amplifiers at minimal drain. The dash-mounted PTT mike also disables the loud-speaker amplifier.

#### 3.4.2.2 Expendable Wire Links

The payout wire is an ultralight-weight assault wire used by the Canadian Signal Corps. The wire, manufactured by the Canada Wire and Cable Company, Toronto, Ontario, consists of a parallel pair of solid aluminum conductors of #23 gauge, polyethylene-insulated, for voice frequency telephone service. It is available in 1/4 and 1/2 mile coils, universally wound.

The D.C. resistance of the wire does not exceed 125 ohms per 1000 loop feet. A one-half mile coil is approximately six inches in diameter and four inches long, with a weight of 3.9 pounds.

The cable is tested at an average payout speed of 25 mph and is designed to withstand a breaking load greater than 25 pounds for the insulated pair.

The communication payout line is carried in a container (Figure 3-26). The container has four individual cans, each containing a reel of wire one-half mile long. The reels pay out wire from the center of the reel as the vehicle advances. Each reel can be interconnected by means of wire crimps to give the vehicle a range of two miles, or they may be used individually to conserve wire. The other end of the line attaches to two spring-loaded binding posts located on the reel carrier. Attached to the binding post is a cable with a

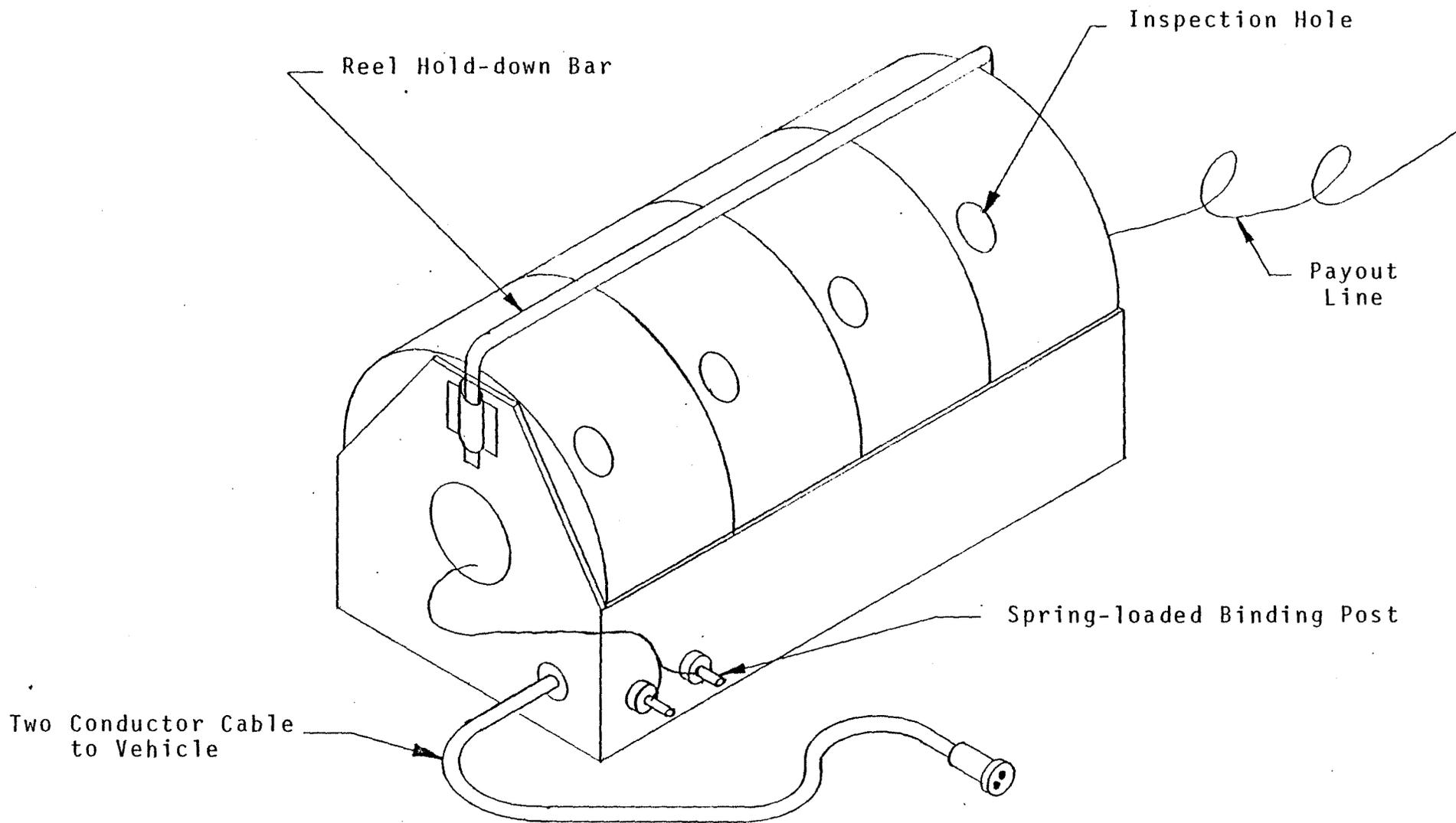


Figure 3-26 - Communication Line Storage Container

connector that plugs into the vehicle at the rear (Figure 3-27).

When the trailer is used, the reel carrier on the vehicle is disconnected and the trailer reel carrier is attached to the vehicle. Figure 3-28 shows the canister mounted on the trailer. The wire pays out through the metal cylinder and through a hole in the rear wall of the trailer. The cylinder prevents wire hang-up on the trailer stretcher supports.

#### 3.4.2.3 Crew Intercommunication System

Rescue crew members can tie into each other and with the Base Station with an Ear-Com system manufactured by Lear-Sigler, consisting of ear-insertion speaker/microphones and belt-mounted control units with PTT switches. The driver's unit also has a remote, under-arm PTT switch to allow "hands free" voice transmission.

The Ear-Com units plug into front panel receptacles and, if a PTT button is actuated, the Vehicle Dash Unit speaker is disabled.

### 3.5 LIFE SUPPORT

The life-support system for the MERV was initially required to provide sufficient life support for the vehicle operator, passenger and two rescue victims. The service life of the system for the passenger and operator was to be eight hours while on the vehicle. In addition, both the operator and passenger were to have the ability to leave the vehicle for 30-minute excursions. During the excursions, portable life-support systems of shorter duration were to be used. Change-over from the long-duration system to the excursion units was to be safe, quick, and reliable when performed in a contaminated environment.

A significant effort was expended in developing a Chemox-type system, serving as both the on-board and portable life-support systems for the rescue crew members. This system, based on potassium superoxide as the oxygen source, had the least weight requirements by a considerable margin, over other possible choices.

A unit was developed and taken to a prototype stage. The basic canister unit was capable of an 8-hour supply, but had to be improved. The concept was ultimately changed to using two such units, similarly designed but modified for four

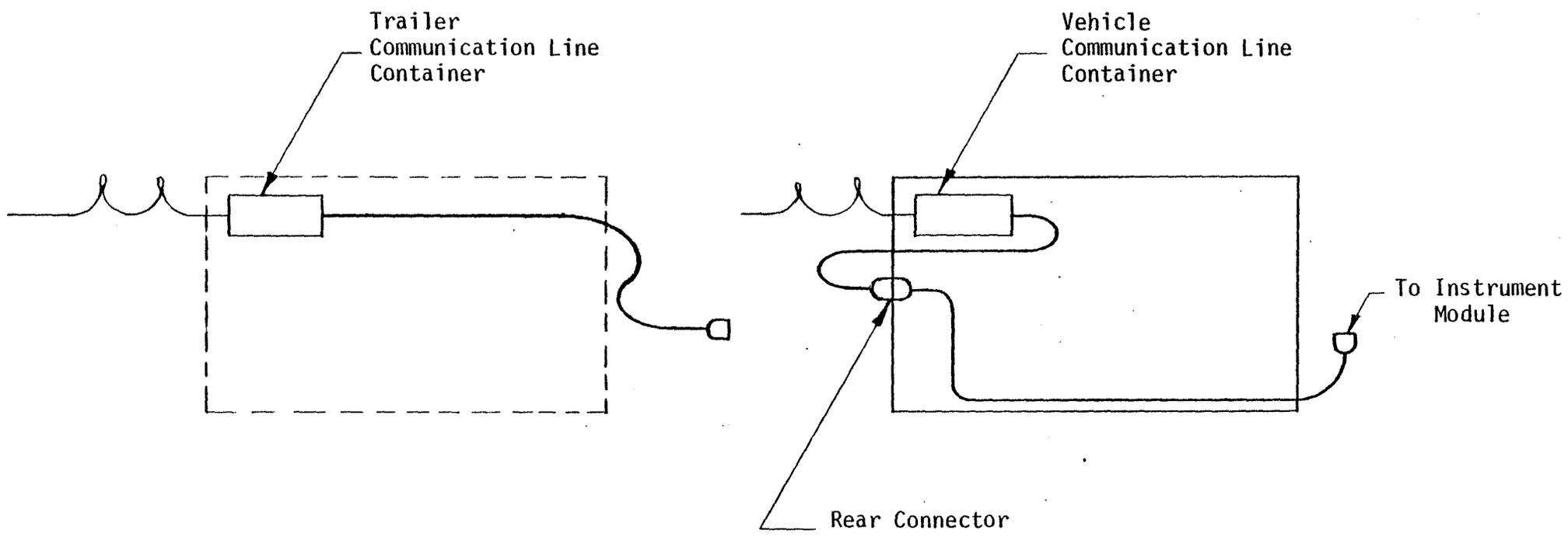


Figure 3-27 - Communication Payout Line

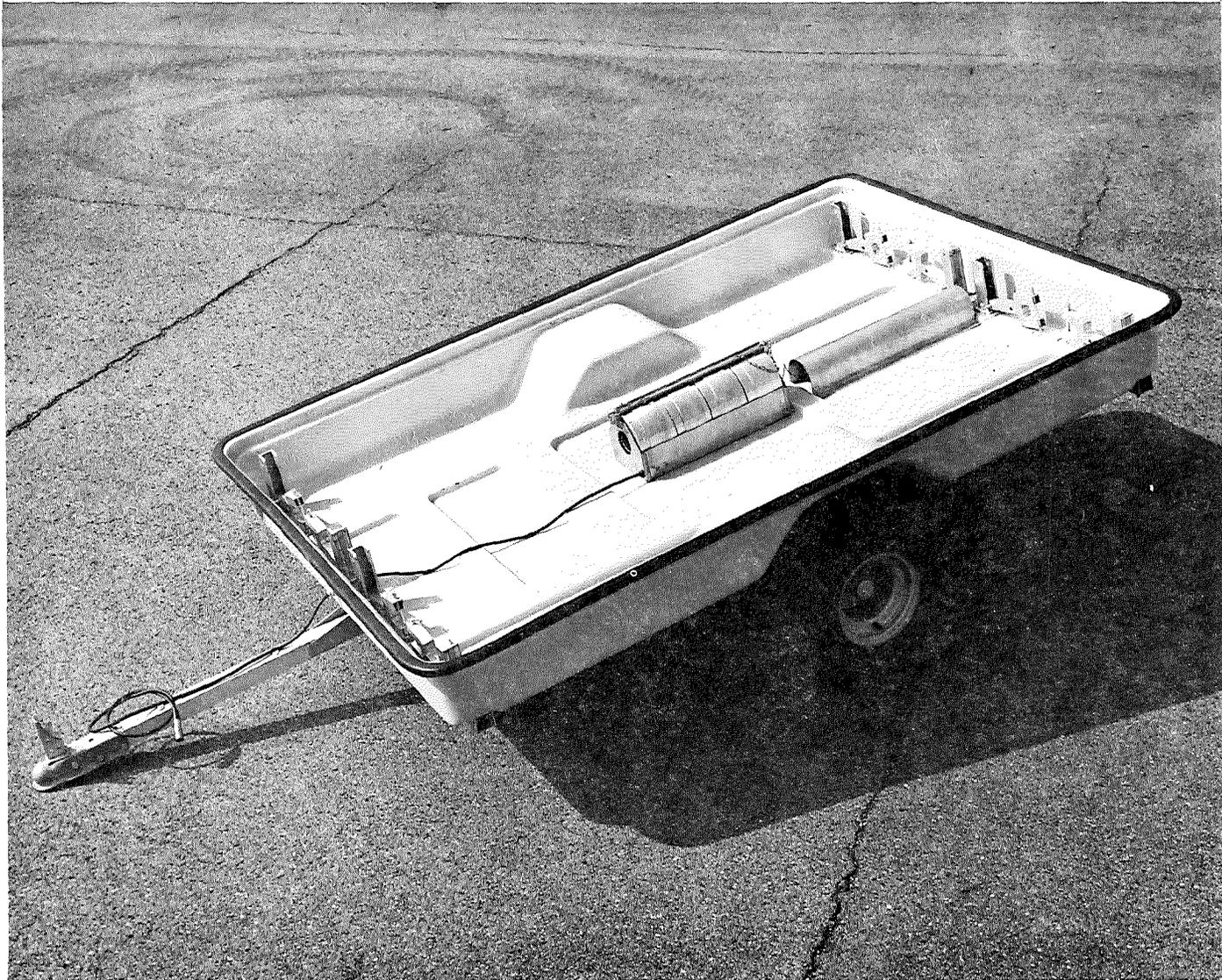


Figure 3-28 - View of Trailer with Reel Carrier

hours, and make an in-mine switch from one canister to the other. The concept proved to be feasible but obtaining approval would have been a significant expenditure of funds. The development of this system is detailed in Appendix A.

With the change in total mission time from the original eight hours to only four, the decision was made to use a commercial life-support unit. Since the Drager BG174A unit was the only one approved for four hours at that time, it was selected. A unit was purchased and the driver cockpit in the MERV was modified to accept the Drager unit. It will now serve as a backrest for the operator.

Standard Chemox units are to be employed for victims. These will be stored in the trailer.

### 3.6 TRAILER

Provisions for transporting injured personnel were required by the contract, with a trailer having a bed that collapses into the vehicle, or a wheeled trailer suggested as a possible alternative.

MSA provided a wheeled trailer (shown in Figure 3-29) with a water-tight molded plastic body. Two heavy-duty stretchers clamp in place on the trailer for victims, with storage space available underneath for tools, life-support apparatus, extra life-support canisters, etc.

#### 3.6.1 General Design Considerations

In deciding on the trailer design, consideration was given to the possible terrain to be covered, comfort of the victims, and available space in the main vehicle. Lack of available space for a folding trailer dictated using a separate trailer unit. A water-tight molded plastic body was decided on for safety in flooded areas; and soft, low-pressure tires, for the comfort of the victims. It was realized that the soft tires would give added rolling resistance. Aluminum frame members were used where possible to keep the total package weight low.

#### 3.6.2 Description of the Unit

Figure 3-30 shows a breakdown of the trailer components, with the appropriate identification key given in Table 3-11. The body is constructed of high visibility yellow ABS plastic, vacuum formed for water-tight construction. Frame members and stretcher supports are constructed of high strength aluminum alloy. The axle was initially aluminum, but was later

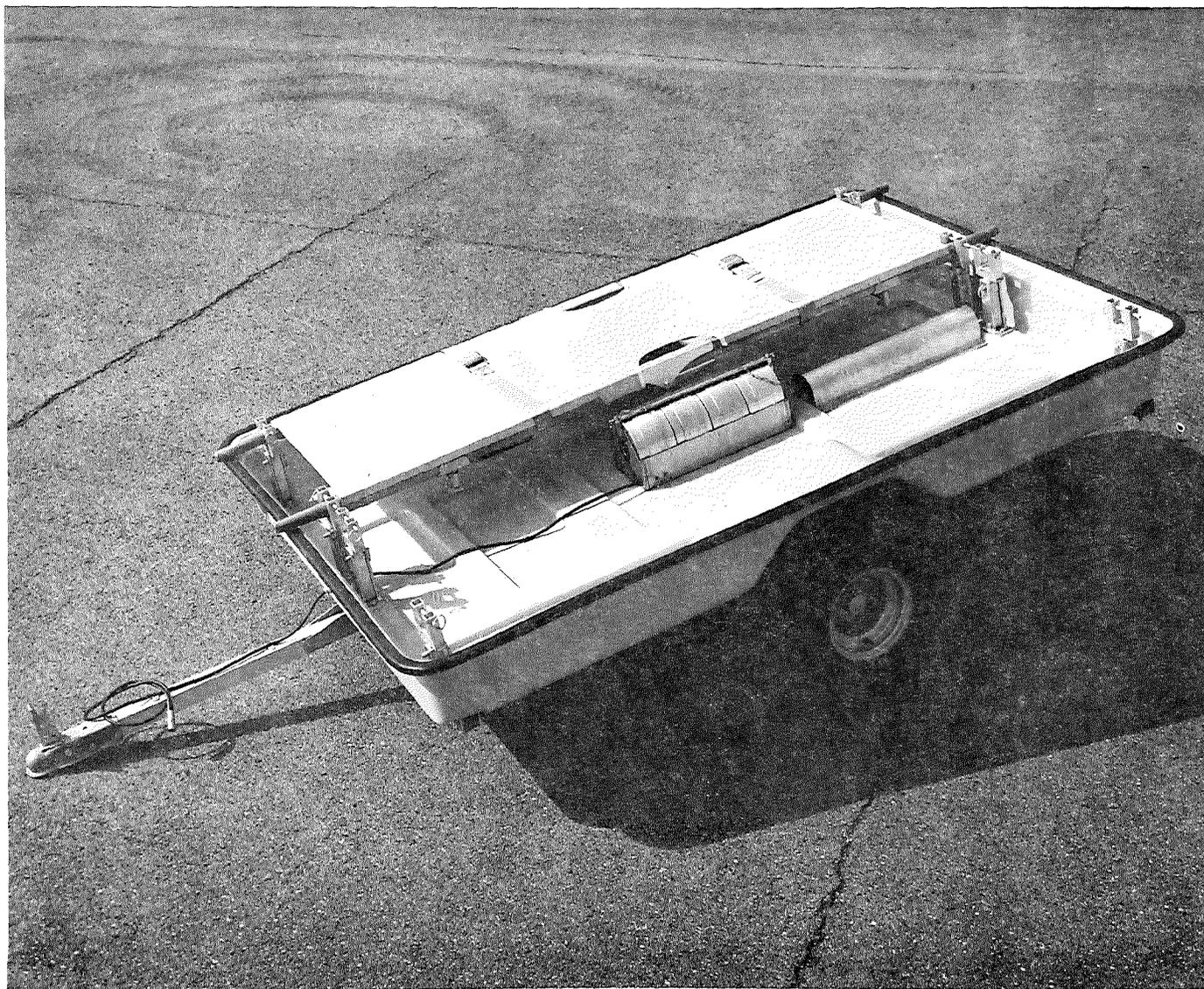


Figure 3-29 - View of Trailer with Stretcher

Figure 3-30 -  
MERY Trailer Components

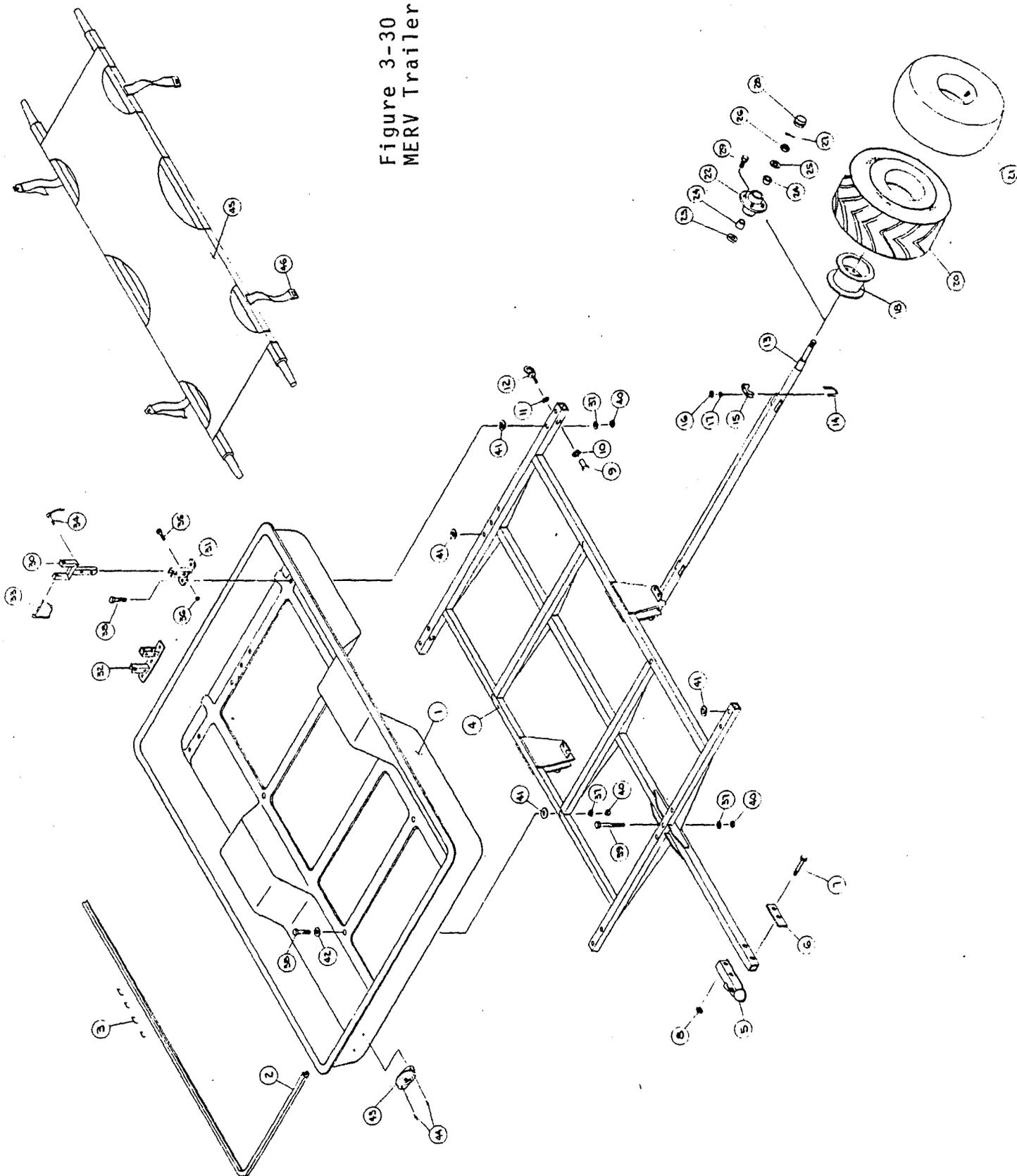


TABLE 3-11 KEY TO TRAILER COMPONENTS (FIGURE 3-30)

NO.	DESCRIPTION
1	Trailer Body
2	Rub Rail Moulding
3	Staple
4	Trailer Frame
5	Coupler
6	Coupler Spacer
7	3/8-24 x 2-1/2 Hex. Hd. Bolt
8	3/8-24 Locknut
9	Holder Insert
10	Washer (Front)
11	Washer (Rear)
12	Flange Eyebolt
13	Trailer Axle
14	U-Bolt
15	Saddle
16	3/8-16 Nut
17	3/8 Spring Lockwasher
18	Wheel Hub
19	Tire (R.H.) Not Shown
20	Tire (L.H.)
21	Inner Tube
22	Hub
23	Oil Seal
24	Bearing
25	Bearing Washer
26	Hex Castle Nut
27	1/8 x 2" Cotter Pin
28	Grease Cup
29	Wheel Bolt
30	Stretcher Support
31	Stretcher Supt. Bk't. (Side)
32	Stretcher Supt. Bk't. (Center)
33	Stretcher Lock Pin
34	Stretcher Supt. Lock Pin
35	3/8-24 x 2" Hex. Hd. Bolt
36	3/8-24 Lock Nut
37	3/8 Dia SAE Flat Washer
38	3/8-16 x 2-3/4 Hex. Hd. Bolt
39	3/8-16 x 4-1/2 Hex. Hd. Bolt
40	3/8-16 Locknut
41	Grommet
42	3/8 Type A Plain Washer
43	Reflector
44	3/16 Dia. Avex Rivet
45	Stretcher
46	Safety Belt

changed to steel for added strength when the aluminum axle bent while crossing logs.

Trailer tires are the low-pressure, cushion type (size 21 x 12 x 8) specified for victim comfort and flotation in soft muddy terrain. The stretchers are MSA's Model 32583. The stretcher suspension is pinned for easy removal, or can be moved to one side to place equipment, tools, etc., in the lower compartment. Safety harnesses are provided for the victims.

### 3.6.3 Performance and Recommendations

The trailer performance proved to be satisfactory in our in-mine tests. Clearance was sufficient for hauling over tracks, although the ride is somewhat rough where track ballast is low between ties. No changes are recommended.

## 3.7 ACCESSORIES

The contract called for the following accessories to be provided:

- headlights - one front and rear,  
minimum 75 watts
- portable high-intensity light with  
charging facility
- horn
- trailer hitch
- lifting lugs for slinging the vehicle  
under a mine-shaft cage

All of these were supplied. In addition, we supplied the following:

- mirror
- 5-hour timer
- fire extinguisher
- speedometer/odometer

### 3.7.1 Description of Accessories

The headlights supplied were U.S.B.M. approved, sealed and rated at 75 watts/32 volts, and manufactured by

Control Products. The bulbs can be replaced with headlights in place.

The portable high-intensity light is a "Carpenter's Light," manufactured by Walter Kidde Company. At a test on a coal surface made by the Bureau's staff at Bruceston, the light gave illumination values at a distance of 20 feet of 1/7 fl at the center of the beam, 0.35 fl at a radius of 7 inches, and 0.07 fl at a radius of 16 inches. The frame was modified by MSA to provide 360° swivel capability.

A compressed-air-operated warning horn was supplied. It sounds a low frequency tone, which carries readily in mine atmosphere conditions.

A five-pound, dry-solids fire extinguisher was mounted on the front cowling of the main vehicle.

A spring-driven 5-hour timer with bell alarm was provided on the instrument panel to give mission length.

A rear-view mirror was provided to assist the driver, especially on back-up operations.

A speedometer-odometer was mounted on the dash panel to the left of the instrument module. The odometer gives readings in hundredths of miles.

### 3.8 HAULING TRAILER

Hauling trailers have been provided for transporting the two MERV units and battery chargers. The trailer, shown in Figure 3-31, is a four-wheeled SNOWCO Model 366 utility trailer manufactured by the Snow Company, Omaha, Nebraska. It has a tilt bed, hydraulically-operated loading winch, and an inertial braking system. Further details are available in the Operations and Maintenance Manual which accompanies this report.

The MERV can be conveniently loaded and unloaded with the aid of the tilt trailer. The unit is loaded backwards for better weight distribution and can be done so under its own power. If not, it can be winched on with the trailer winch.

Figure 3-32 shows the MERV in place, ready for hauling, with the rescue trailer upside down on the deck of the MERV. The MERV is secured with wheel stops and chains front and rear. Taupaulins have been provided for both MERV units and chargers.

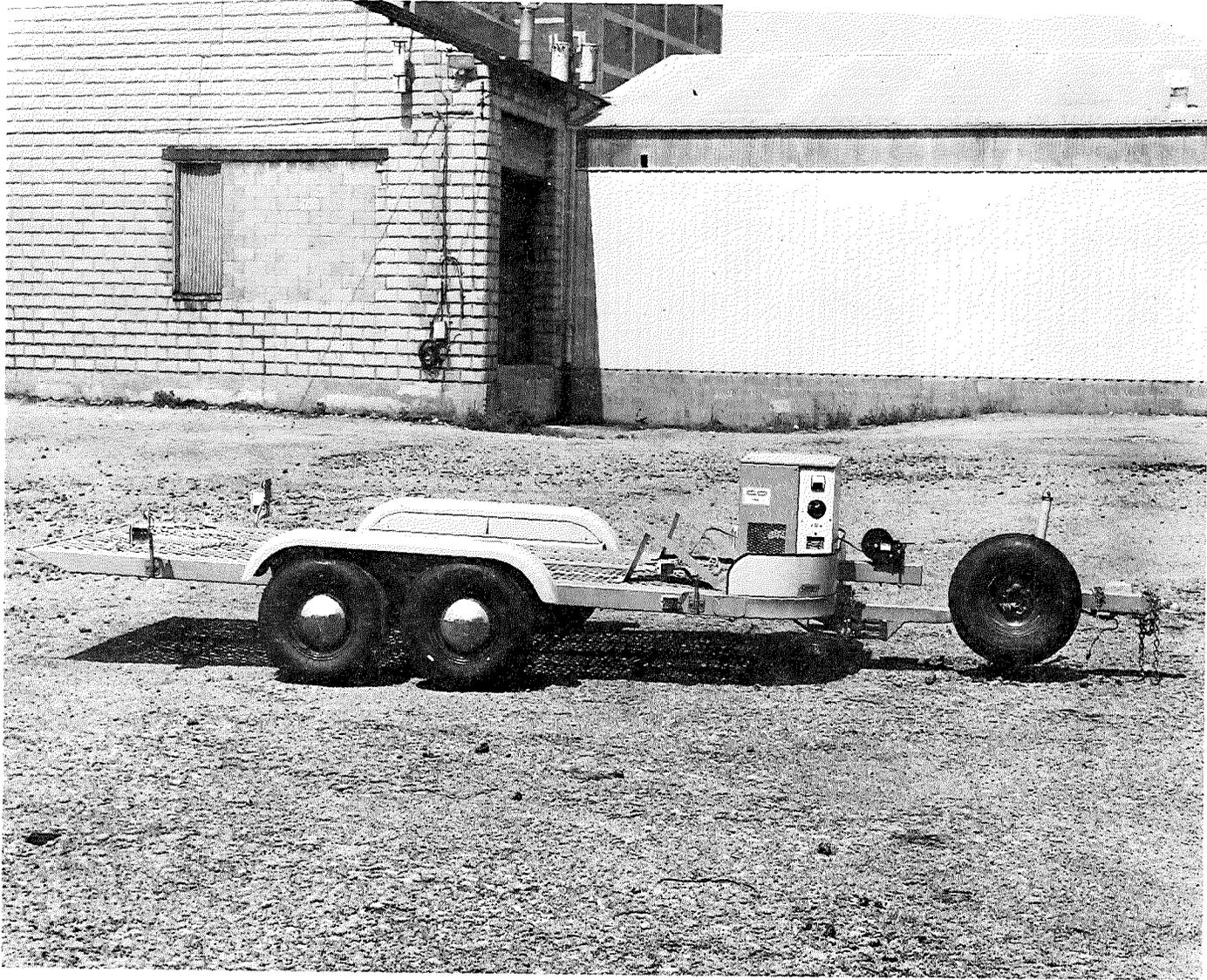


Figure 3-31 - View of Hauling Trailer



Figure 3-32 - View of Hauling Trailer with MERV

#### 4. PROGRAM RECOMMENDATIONS

The basic requirements of a mine rescue vehicle have been achieved in the present MERV, and mine rescue operations based on its use should now be studied and updated. It is our understanding that such studies are being contemplated and we endorse their support.

We believe that the availability of the vehicle makes possible new rescue techniques and procedures which will allow greater exploration of possible disaster sections and more rapid contact with trapped miners with the attendant greater possibility of their rescue. However, we feel that the modification of rescue procedures should be made with the utmost caution based on testing and experience. We recommend a program under which rescue teams would be equipped with at least two vehicles, to retain the concept of a backup team, and that they be trained and practice under simulated disaster conditions.

Based on these training experiences, rescue mission time and distance limitations could be established with appropriate safety factors. Rescue techniques could be improved and the need for additional equipment or modifications could be determined.

Our first purpose is to prevent disasters but, should one occur, we feel that the rescue vehicle could minimize the loss of life to trapped or isolated miners. We recommend that provision be made to make the best and safe use of it.

We believe that the MERV unit has proved itself sufficiently in this program to warrant the immediate construction of companion units and to make plans for providing similar unit pairs to strategic locations throughout the country. Without such future planning, widespread availability of MERV units for mine rescue personnel may stretch several years down the road.

A FIRE BOSS VEHICLE appears to be a possible spin-off from the rescue vehicle. With ever longer runs to make and the shortage of qualified personnel, adequate fire bossing is becoming an increasing problem. A simplified vehicle of the rescue type equipped with instruments and communications could enable the fire boss to make his inspection runs more quickly and allow him to cover more sections and still do an effective job.

The methane readings, for example, could be taken by the use of probes from the vehicle and the concentrations could be recorded on strip chart or magnetic tape. Carrier-frequency communications equipment could provide constant contact with the surface as long as trolley or telephone lines were available so that conditions could be reported immediately and corrective action begun if needed.

Although a fire-boss vehicle such as described could be produced with a minimum of development, we suggest that it be done under the sponsorship of the Bureau of Mines so that inspection techniques made possible by its use are investigated. If new techniques and procedures can be developed to more quickly and effectively determine and certify the mine conditions, it should be done under the auspices of the Bureau.

5. APPENDICES

APPENDIX A

STUDIES ON A CHEMOX-TYPE UNIT  
AS THE  
MERV PRIMARY LIFE SUPPORT SYSTEM

## APPENDIX A - STUDIES ON A CHEMOX-TYPE UNIT AS THE MERV PRIMARY LIFE SUPPORT SYSTEM

This section summarizes the study conducted by MSA in furnishing a basic life-support system for the MERV for the original 8-hour mission concept. When the mission length was reduced to four hours, the need for further development of this concept, along with the rather extensive requirements for obtaining approval of the unit, was eliminated.

### GENERAL DESIGN CONSIDERATIONS

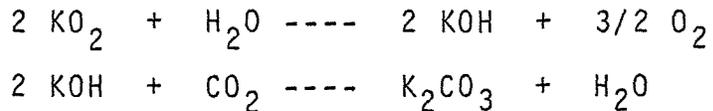
In designing a Life Support System for the Mine Emergency Rescue Vehicle, the first major consideration encountered was the type of self-contained system to be used. Since the Request for Proposal had required that a rebreather type of system be used on the vehicle, three possible alternatives were considered. Each of the following three considerations could be designed to be demand responsive to meet the respiratory needs of the wearer:

- (1) Compressed Oxygen System
- (2) Chemical Oxygen from Chlorate Candles
- (3) Oxygen from Potassium Superoxide.

In the first of these, a compressed oxygen system, a supply of oxygen is contained in a high pressure cylinder. From the cylinder, oxygen is regulated and supplied to the wearer through an admission valve. The  $\text{CO}_2$  content of the exhaled air is removed by a separate  $\text{LiOH}$  (lithium hydroxide) canister inserted into the system. The major disadvantage of this system is the fact that it requires both an oxygen supply and a  $\text{CO}_2$  absorber. These functions ( $\text{O}_2$  supply and  $\text{CO}_2$  removal) must be performed by separate units.

The second consideration, chemical oxygen from chlorate candles, is essentially the same as the compressed oxygen system except that the oxygen source is a chlorate candle instead of compressed gas. In this system, a continuous supply of oxygen is maintained by a pressure sensitive transducer that electrically activates additional candles when the pressure at some location in the system falls below a predetermined value. The major advantage of the chlorate candle system over the compressed gas system is that of improved storage life. However, the chlorate candle system still requires a  $\text{CO}_2$  remover separate from its oxygen supply.

In system Number 3, oxygen is supplied by a chemical bed of potassium superoxide ( $\text{KO}_2$ ). The potassium superoxide reacts with the moisture and  $\text{CO}_2$  in an exhaled breath to liberate oxygen according to the following two-step reaction:



Thus, oxygen is liberated and  $\text{CO}_2$  absorbed in the same chemical bed. This then is the main advantage of the  $\text{KO}_2$  system over the compressed oxygen or chlorate candle systems. Additional advantages are realized from the fact that a  $\text{KO}_2$  system is inherently demand responsive. That is, the quantity of oxygen liberated is a direct function of the user's metabolic activity. As the respiratory rate of the user increases or decreases, so does the liberation and absorption rate of the potassium superoxide.

Thus, because of its relative simplicity and demand responsive characteristics, the potassium superoxide system was chosen as the oxygen source for the MERV Life Support Equipment.

### INITIAL DESIGN CONCEPT

Initial design philosophy for the Mine Emergency Rescue Vehicle Life Support System was to incorporate two rebreather-type life support systems as an integral part of the vehicle. This system was to provide sufficient life support to the driver and passenger for an eight-hour period. In addition, the ability to disconnect from the vehicle life support system and engage to units of shorter duration for excursions from the vehicle was necessary. Vehicle-to-excursion (and vice versa) exchange was the major mechanical problem encountered in this design concept of the MERV Life Support System. Using the standard Chemox apparatus as the central apparatus design, the changeover problem was solved through the design of a series of low-entrapped, dead-volume, quick-disconnecting unions and a specially designed low dead-volume manifold assembly for the Chemox apparatus. The quick disconnecting unions were designed with an entrapped dead volume of approximately 5 cubic centimeters per union assembly. The low dead-volume was attained by means of automatic shutoff valves that are forced open when the valves are engaged. The quick disconnecting unions were used on the various breathing hoses to facilitate rapid and safe engagement and disengagement. The manifold assembly was similarly designed with an entrapped dead volume of approximately 10 cubic centimeters.

The low dead-volume manifold assembly enabled the one-hour Chemox canisters to be safely inserted and removed from the breathing circuit (Ref.: Figure 1).

A prototype system adhering to the above concept and consisting of the following equipment was built and demonstrated to the Bureau of Mines:

- (1) Ultravue Facepiece.
- (2) Chemox Breathing Bag and Modified Breastplate.
- (3) Low Dead-volume Manifold.
- (4) Inhalation and Exhalation Breathing Hose Assemblies, fitted with quick disconnecting unions.
- (5) Eight-hour Chemical Canister, mounted on the vehicle.
- (6) One-hour Chemox Canister for excursions from the vehicle.

Evaluation of the above prototype system rendered the design inadequate because of the marginal restart characteristics of the eight-hour chemical canister at temperatures of 60°F and lower. Because of the marginal cold restart characteristics of the canister, the ability to restart the eight-hour canister after an excursion from the vehicle was seriously jeopardized. Thus, the initial system design concept required modification.

#### FINAL DESIGN CONCEPT

Through the use of catalyzed potassium superoxide, an initial start of the eight-hour canister in a 60°F ambient temperature could be encured. Thus, a life support system utilizing one chemical canister to be used both on and off the vehicle for a period of four hours was considered. The low dead-volume quick-disconnecting unions discussed previously would be used to provide rapid and safe exchange of the canister at the end of four hours. Once again, a prototype system was built and demonstrated to the Bureau of Mines. This prototype system consisted of the following equipment (Ref.: Figure 2):

- (1) Ultravue Facepiece.
- (2) Exhalation and Inhalation Breathing Tubes, equipped with quick disconnecting unions.
- (3) Modified Chemox Breastplate and Breathing Bag Assembly.
- (4) Four-hour Chemical Canister.
- (5) Harness Assembly for Four-hour Chemical Canister.

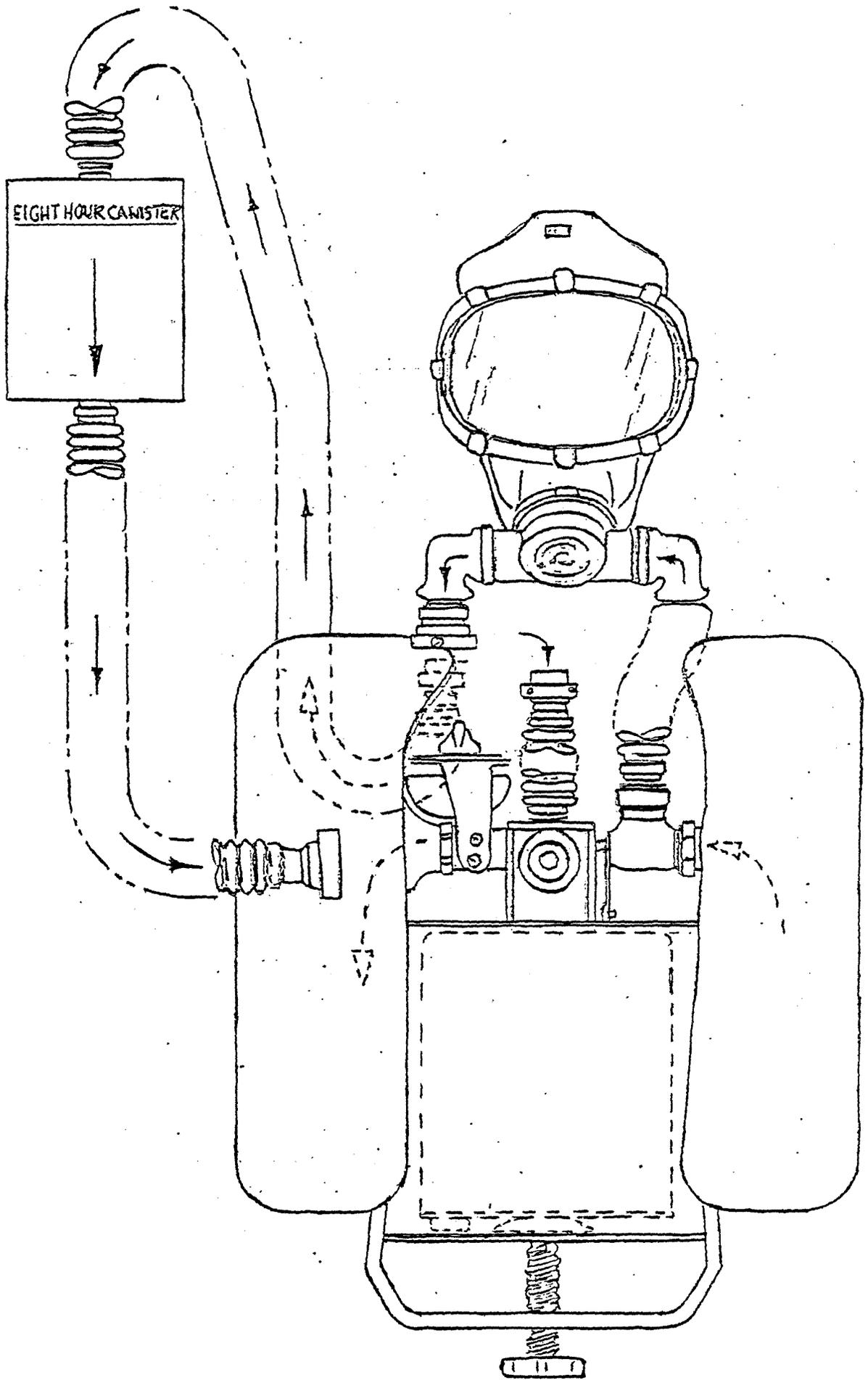


Figure 1 - Initial Design Concept

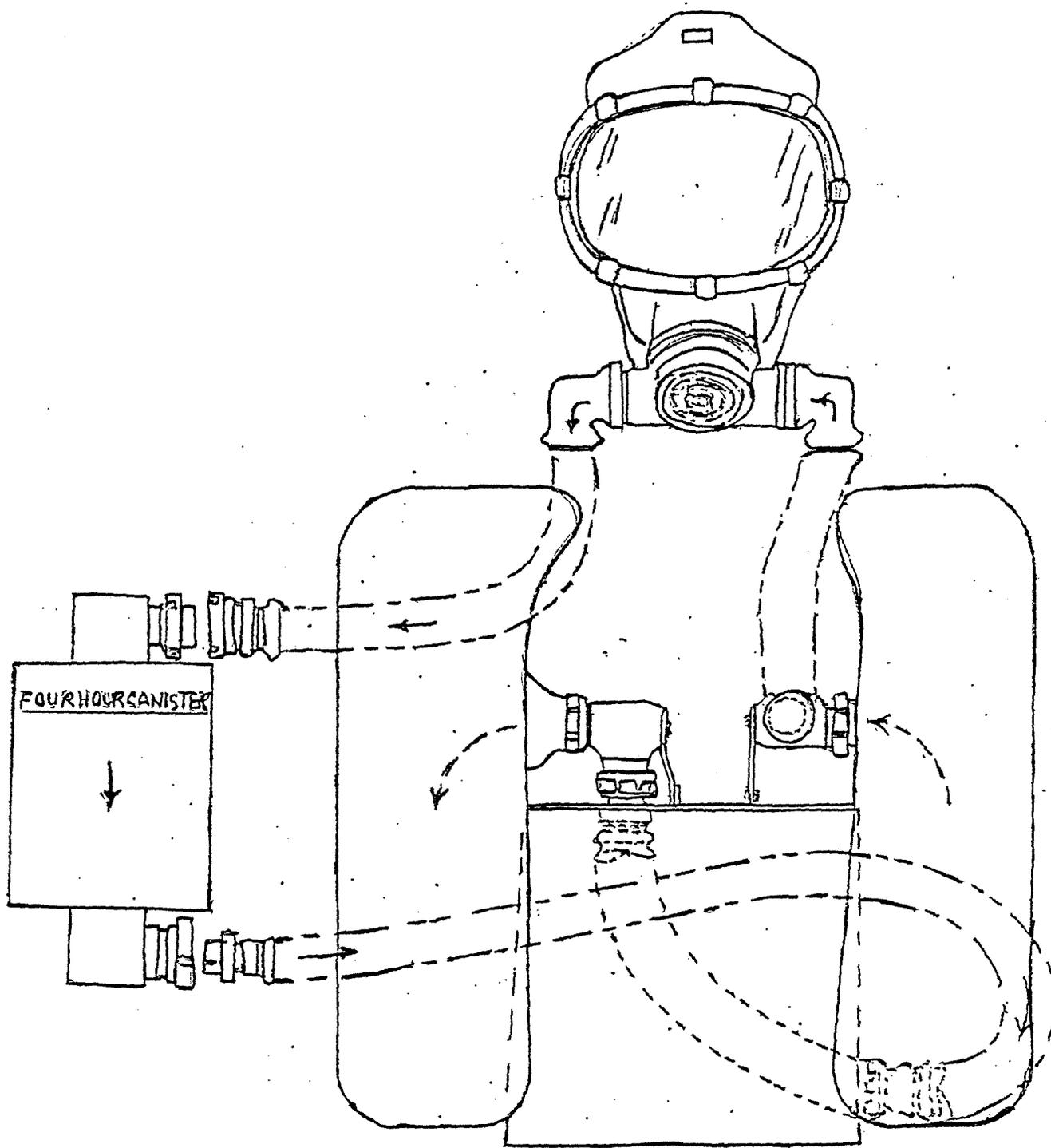


Figure 2 - Final Design Concept

In addition to solving the cold restart problem, the second prototype system was considerably less complicated and provided less interferences with normal head and arm movement than the initial system design. Tests conducted to verify cold start ability and to verify an adequate supply of oxygen for the following work loads were successful:

- (1) Two hours - walking at the rate of 1 mph.
- (2) One hour - Test #1 per Code of Federal Register, Part 11, Subpart H, Section 11.85-14 (Ref.: Appendix C).
- (3) One hour - Test #4 per Code of Federal Register, Part 11, Subpart H, Section 11.85-15 (Ref.: Appendix C).

Thus, a life support system design corresponding to the second prototype was adopted for the Mine Emergency Rescue Vehicle.

Life support equipment to be supplied for rescue victims consists of two standard Chemox apparatus equipped with one-hour Chemox canisters.

The remaining content of this section of the report discusses the design of the various system components. An instruction procedure for proper use and care of the Life Support System is also discussed.

## APPARATUS COMPONENT DESIGNS

### CHEMICAL CANISTER

The first consideration in the design of a breathing apparatus canister is the quantity of potassium superoxide required to satisfy the respiratory needs of the user. Size of the canister is dependent on the metabolic requirements of the user and on certain characteristics of the chemical and chemical bed design. Specifically, the variables are:

- (1) The  $O_2$  consumption rate of the user.
- (2) The metabolic respiratory quotient of the user (R.Q.) man.
- (3) The oxygen available in the  $KO_2$  granules.

- (4) The ratio of  $\text{CO}_2$  absorbed to  $\text{O}_2$  evolved in the chemical bed (R.Q.) canister.
- (5) The percentage of chemical bed which is used (utilization efficiency) before the ability to remove  $\text{CO}_2$  and generate  $\text{O}_2$  is significantly altered.

The metabolic respiratory quotient (R.Q.) is the ratio of  $\text{CO}_2$  exhaled by the user to the oxygen he absorbs. Data dealing with individual R.Q. is available and appears to be relatively consistent throughout the literature. Published values of R.Q. values vary from 0.8 for low work rates to 1.2 at very high work rates.

The oxygen available in  $\text{KO}_2$  granules is approximately 223 cubic centimeters of oxygen per gram of  $\text{KO}_2$ . Potassium superoxide produced commercially is required to be tested and to conform to the available oxygen requirements of MIL-O-15633C, September, 1964, which specifies a minimum of 215 cc's of  $\text{O}_2$  per gram of  $\text{KO}_2$ .

The ratio of  $\text{CO}_2$  absorbed to  $\text{O}_2$  generated in a potassium superoxide bed is referred to as the canister respiratory quotient (R.Q.). Since the percentage of chemical used is dependent on the canister and apparatus design, an actual figure for this quantity must be assumed for the initial canister sizing. Experience has indicated a chemical utilization of 70% to be adequate for initial sizing.

Because the canister design parameters are uncertain quantities, preliminary design must be based on approximate calculations and actual values later established through testing. Initial calculations for the subject canister design indicated that approximately 3,000 grams of potassium superoxide would be required to fulfill the respiratory needs of the driver or passenger for a period of eight hours on the vehicle. Subsequent testing established that 2570 grams of  $\text{KO}_2$  would be sufficient. Testing of various chemical bed configurations indicated that a split bed design of uniform thickness provided lower  $\text{CO}_2$  levels in the inhalation breathing tube than a split wedge-shaped bed. The uniformly thick split chemical bed charged with 2570 grams of  $\text{KO}_2$  provided a sufficient quantity of oxygen and adequately scrubbed the exhaled  $\text{CO}_2$  from the system to meet the requirements of CFR, Part 11, Subpart H. The overall canister shape and dimensions required to house the chemical bed and provide sufficient passage for the flow of air was a rectangular box measuring 10 1/4 in. long by 8 in. wide and 4 1/2 in. high.

With the canister dimensions and bed geometry established, further tests were conducted to evaluate and improve the cold-start characteristics of the unit. Tests conducted with the apparatus soaked at a temperature of 60°F showed the starting capabilities of the unit in a simulated mine environment to be at best marginal. A probable explanation for the poor cold-start characteristic was the condensing of moisture out of the exhaled air as it passed through the exhalation breathing tube. If the chemical reaction could be initially activated, it was felt that the exothermic nature of the chemical reaction would warm up the entire system enough to correct the condensation problem. Thus, efforts were directed at obtaining a successful initial start. The main result of the cold-start testing efforts was the addition of catalyzed superoxide reaction. Although catalyzed  $KO_2$  did solve the poor low-temperature start characteristics of the canister, the addition of catalyzed  $KO_2$  to the system was not done without creating additional problems. The unfortunate characteristic of catalyzed  $KO_2$  is that, upon use, the catalyzed  $KO_2$  adheres together, thus creating a blockage of air flow. Thus, in order to use the catalyzed  $KO_2$ , a system of arranging the chemical had to be designed that would circumvent the blockage problem. Blockage was prevented by arranging the catalyzed  $KO_2$  in a pleated screen that provided air passages through the chemical at all times (Ref.: Figure 3).

Although the addition of catalyzed  $KO_2$  to the canister solved the low temperature initial start problem, the ability to restart the chemical reaction was not improved. Because of this, a major change in the design philosophy of the MERV Life Support System was proposed. This change involved restyling the overall system from that of an eight-hour supply fixed to the vehicle with smaller excursion units to that of a four-hour unit that could be used both on and off the vehicle and replaced by another four-hour unit when expired.

Calculations similar to those used to establish the initial eight-hour canister size verified that the canister should be adequate for the following work load:

- One hour - walking at the rate of 1 mph.
- One hour - Test #1 per Code of Federal Register, Part 11, Subpart H, Section 11.85-15 (Ref.: Appendix C).
- One hour - Test #4 per Code of Federal Register, Part 11, Subpart H, Section 11.85-15 (Ref: Appendix C).

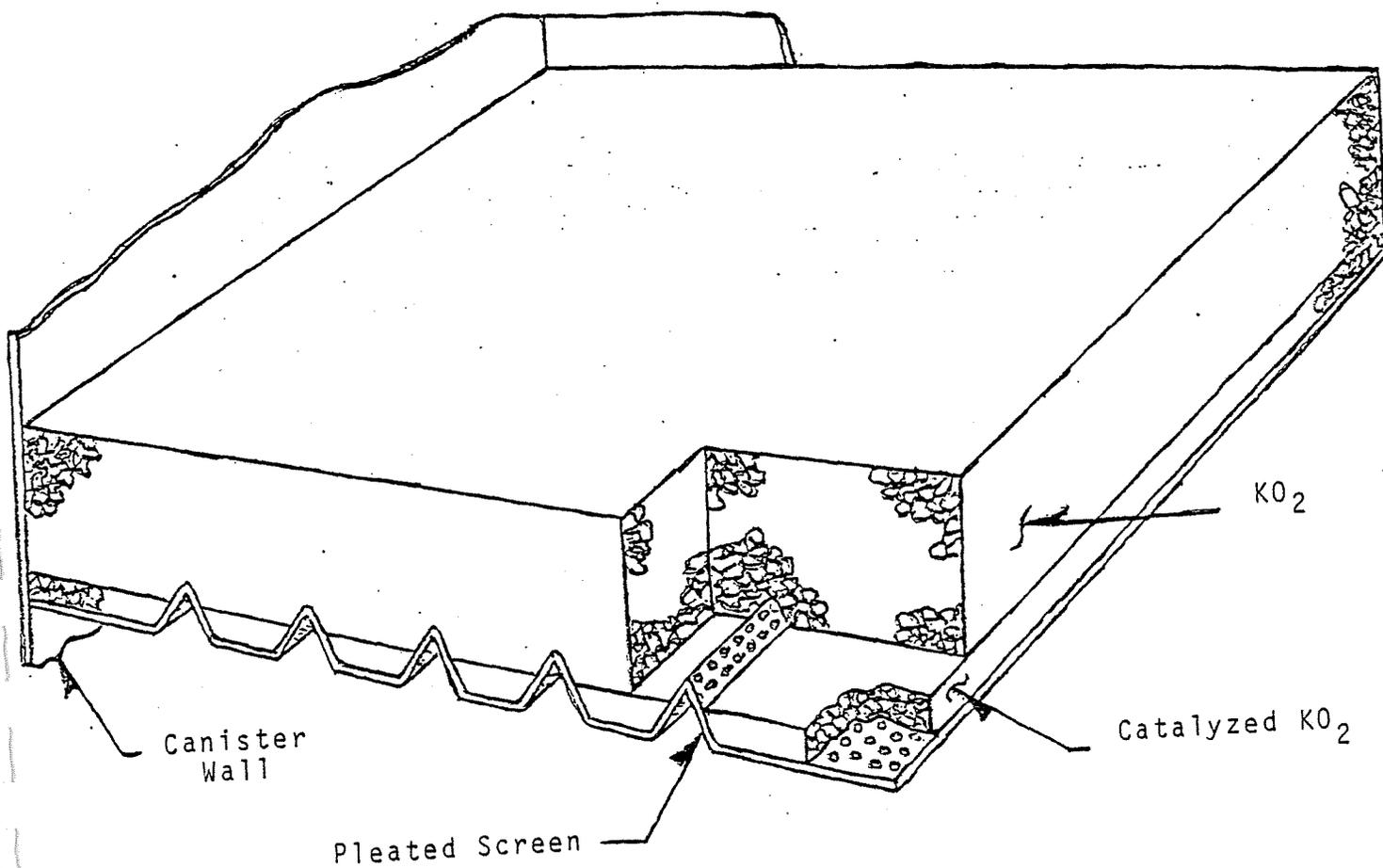


Figure 3 - Pleated Screen Arrangement

Follow-up testing further confirmed that the canister was adequately sized for the suggested four-hour work load.

In order to provide an instantaneous supply of oxygen during the early minutes of use and to aid in starting the chemical reaction, four chlorate candles are embedded into the chemical bed. The candles are activated by a Bouchon-type primer system. The primer is contained within an outer housing designed to permit candle firing in a hostile environment with no danger of sparks being emitted to the atmosphere by the candle primer. A locking device fastened to the cap of the housing holds the firing mechanism in a loaded position and prevents premature firing of the candles. During the initial stages of use, the candles are activated by squeezing the locking device and cap together to release the lock and turning the cap 90° in a counterclockwise direction. Each candle will burn for approximately three minutes. Due to the size of the canister, two candles will be required to ensure a successful start. The first candle is to be fired immediately upon donning the apparatus and the second to follow approximately three minutes later. A total of four candles have been provided in the canister. Two candles will be used for the initial start of the canister. The two additional candles are standby units to be used in the event of an emergency or to aid in starting the canister at temperatures below 60°F.

Since the generation of oxygen from potassium superoxide is an exothermic reaction, the chemical canister does become uncomfortably warm during use. In an attempt to retain the heat in a cold-start situation and to protect the user from the hot canister surfaces, the canister is covered with an aluminum-coated asbestos jacket. The jacket is provided with snaps so that access to the firing devices may be readily obtained. (Reference: Figure 4.)

The exterior of the canister is also equipped with a handle and tabs required for mounting to the special four-hour canister harness.

#### HARNESS AND CARRIER

With the change in system design philosophy, it became necessary to provide a means of carrying the four-hour canister during excursions from the vehicle. The four-hour canister was to be mounted on the vehicle for use when riding. For excursions, a quick and reliable means of transferring the canister from the vehicle to the individual was required. In addition, the means of mounting the canister on the individual had to be smoothly integrated with the breathing bag and breastplate assembly of the standard Chemox apparatus, since these would remain a vital part of the entire apparatus design.

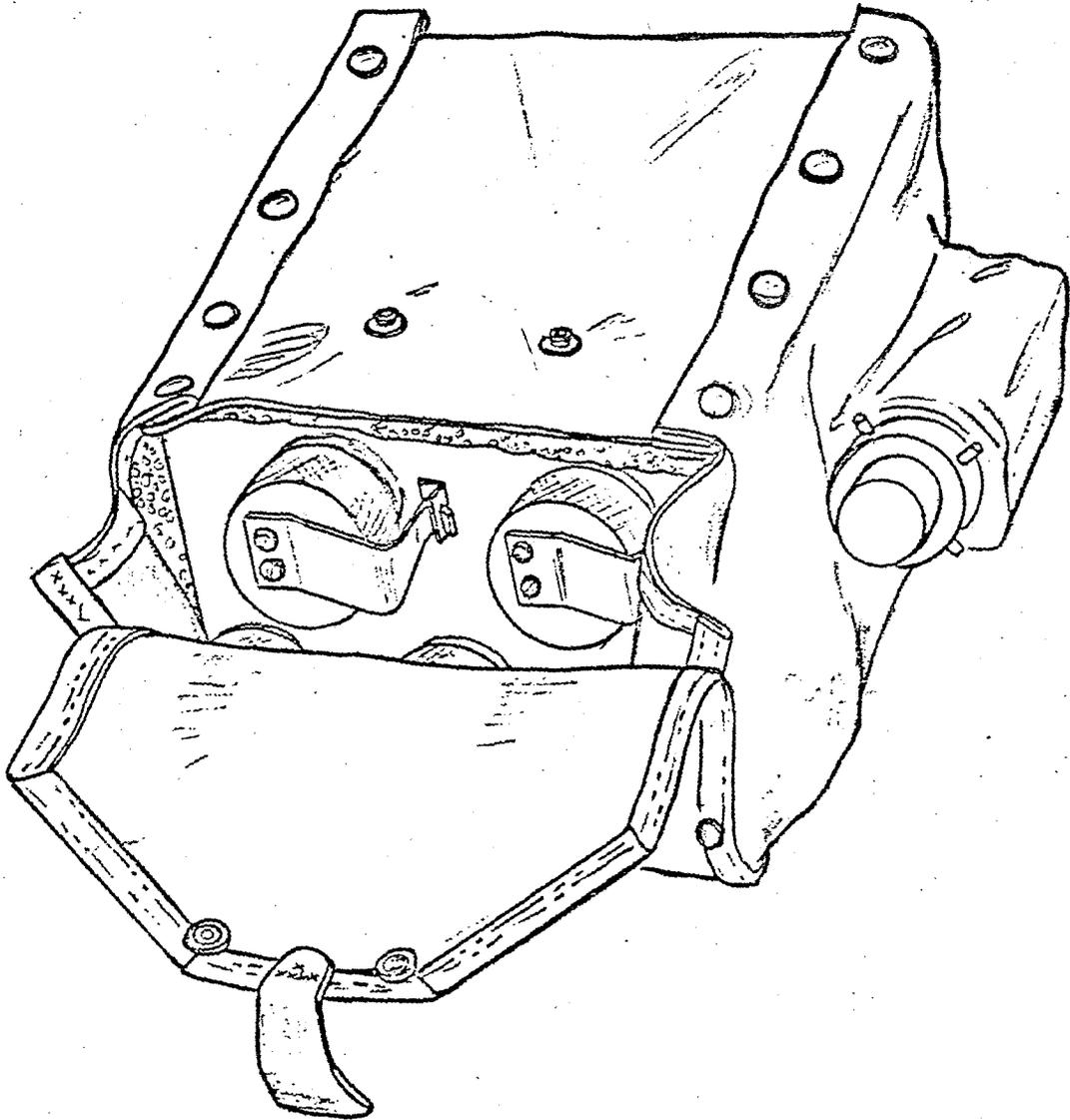


Figure 4 - Four-Hour Canister

Preliminary investigations were performed to determine the most ideal method of affixing the four-hour canister to the individual. The basic concepts evaluated were the following:

- Back canister mount.
- Side canister mount with a harness suspended from the Chemox harness.
- Hip and side mount employing a harness assembly separate from that of the Chemox harness.

The back canister mount was eliminated because of difficulty encountered when transferring the canister from the vehicle to the individual. The operations required to perform this task resulted in an intolerable tangling of the breathing tube assemblies.

The concept of a side canister mount suspended from the Chemox harness assembly was eliminated for the same reason the back canister was ruled out.

Although a second complete harness assembly was entrained, the hip and side mounting concept appeared to be the most feasible design. Using this concept, a separate harness assembly was developed that, when properly donned, did not interfere with components (breathing bag and breathing hoses) of the standard Chemox apparatus.

The four-hour canister harness (Figure 5) consists of an adjustable shoulder strap, a waist strap, and a polycarbonate carrier. The carrier and harness assembly is donned before entry into the mine and remains donned throughout the rescue mission. The harness carrier has been designed so that the canister can be mounted securely to the carrier and easily removed for mounting on the vehicle.

#### QUICK DISCONNECTING UNION

Low entrapped dead-volume quick-disconnecting unions (Figure 6) are used to join the breathing-tube assemblies to the four-hour canister. As previously mentioned, the unions have been designed with a system of automatic shut-off valves which limit the enclosed dead volume of each union assembly to only 5 cc's each. The low dead-volume characteristics permit canister exchange to be performed in a hostile environment without danger of contaminating the entire breathing circuit.

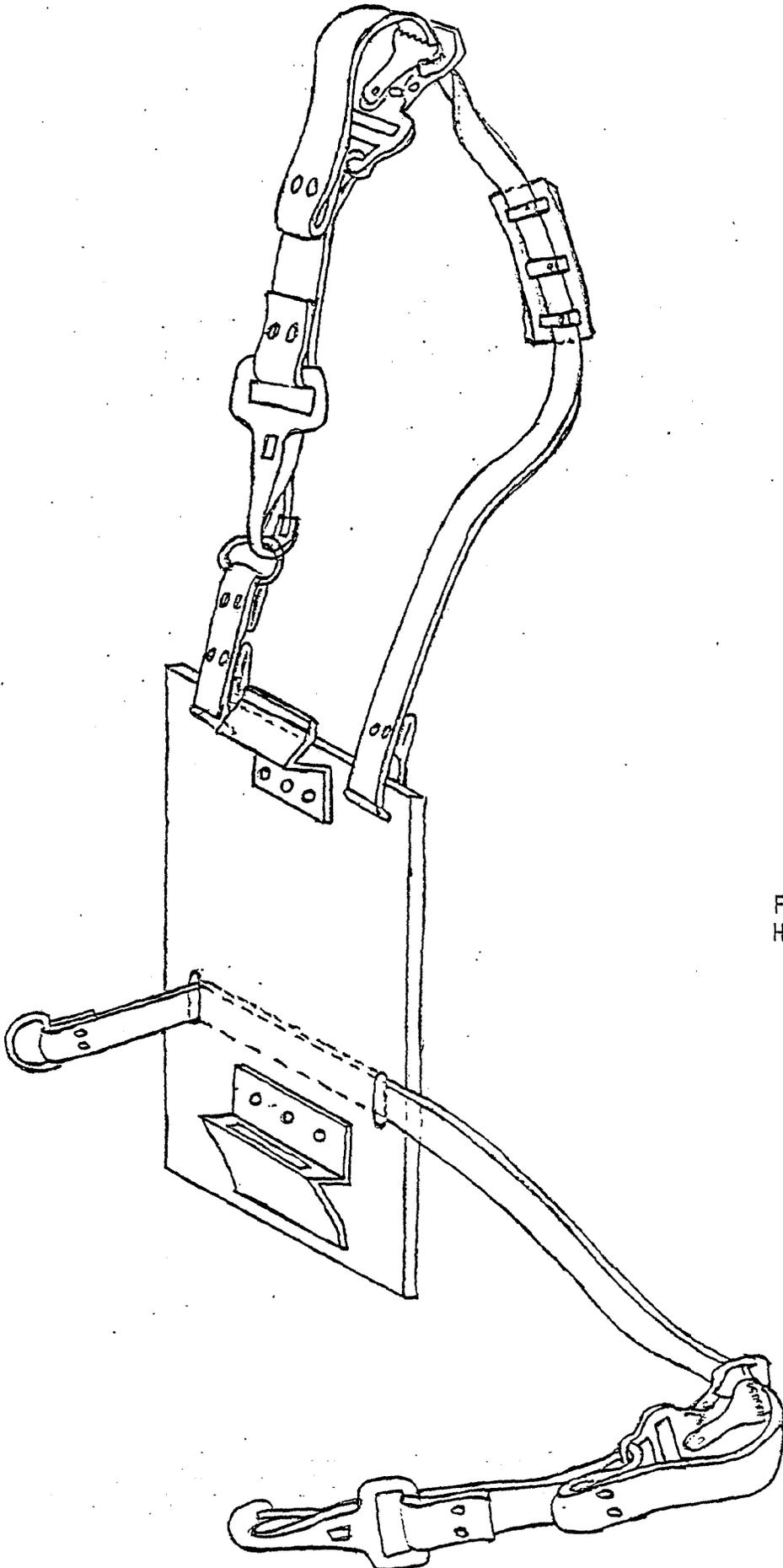


Figure 5 -  
Harness Assembly

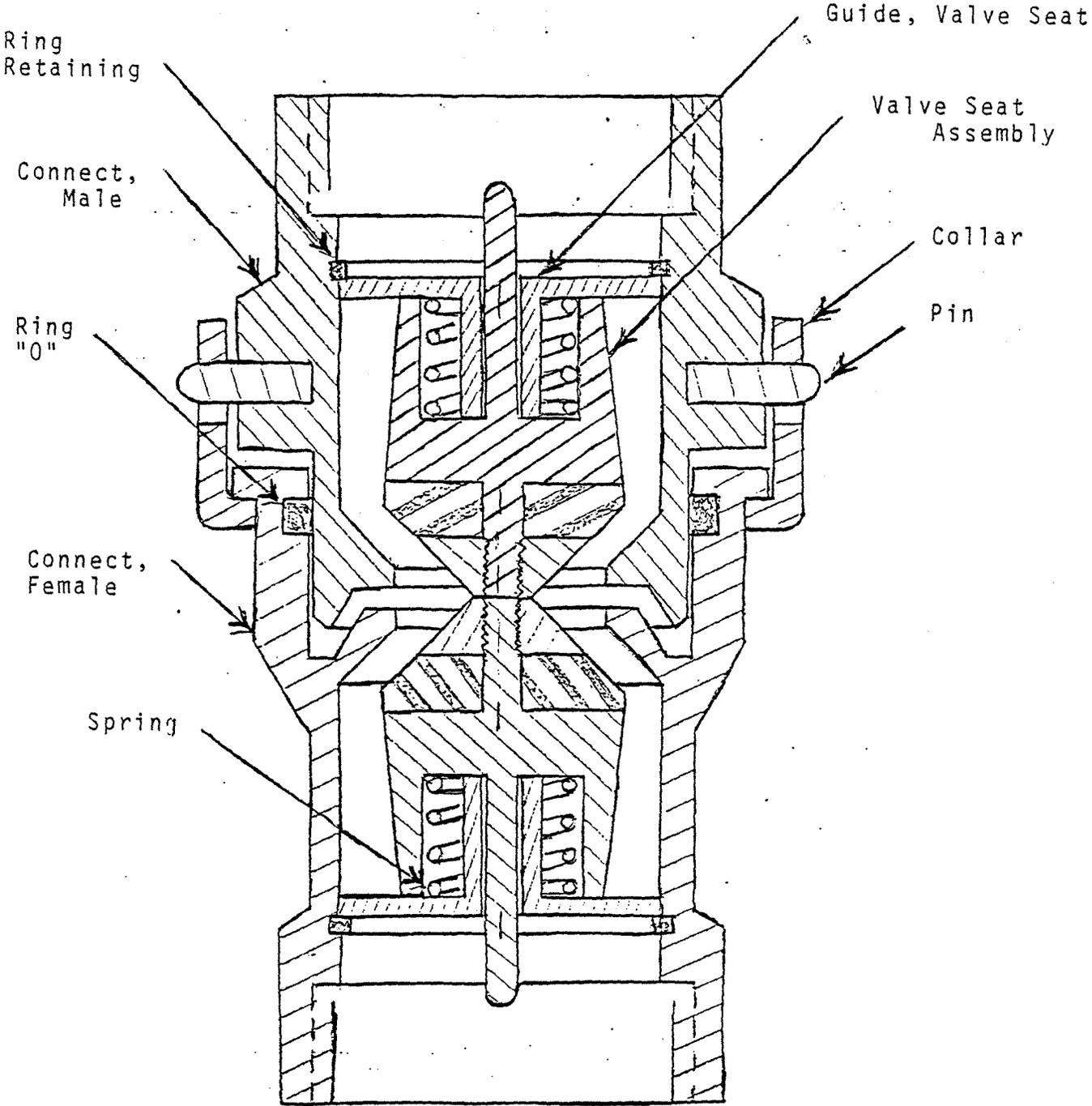


Figure 6 - Quick Disconnect Assembly

## BREASTPLATE AND BREATHING BAG ASSEMBLY

The breastplate and breathing bag assembly (Figure 2) for the MERV Life Support System is a modified Chemox breastplate and breathing-bag assembly. Modifications were made to adopt the four-hour canister to the breathing circuit and to eliminate use of the one-hour Chemox canisters. Specifically, the Chemox manifold was removed and the breathing-tube lengths and breathing-bag connections were changed to incorporate the four-hour canister to the system.

## FACEPIECE

The standard Chemox Ultravue facepiece was used.

## PROCEDURE FOR USE AND CARE

PREPARATION FOR USE

Preparation of the breathing apparatus for use consists of the following steps:

1. Donning the breastplate and breathing-bag assembly.
2. Donning the four-hour canister harness and carrier.
3. Engagement of the four-hour canister.
4. Donning the facepiece.
5. Starting the chemical canister.
6. Operational check.

Each of these steps is explained in detail in the remaining parts of this section.

1. Donning the breastplate and breathing bag assembly.

The breastplate and breathing bag assembly is donned by passing the crossover of the assembly shoulder straps over the head. Holding the breastplate against the chest, reach around back for the free ends of the shoulder straps and snap the straps to the D-rings located where the shoulder straps join the breastplate. Next, pass the waist strap around the body and fasten the two snaps provided on the wrist strap to the lugs on the lower corners of the breastplate. The waist strap can then be adjusted to the desired tightness.

2. Donning the four-hour canister harness and carrier.

Pass the shoulder strap of the four-hour canister harness over the head onto the right shoulder and adjust the shoulder strap to the desired length. The waist strap for the four-hour canister carrier is then passed around the body, fastened, and adjusted for a comfortable fit. These operations will locate the carrier plate on the left hip of the wearer. The carrier plate can be moved along the waist belt to any desired position.

### 3. Engagement of the four-hour canister.

The next step in the preparation-for-use procedure is to connect the four-hour canister into the system. This is done by matching the black and silver female quick-disconnecting unions on the exhalation and inhalation breathing tubes with the corresponding black and silver male unions on the canister. For this operation, the canister should be sitting on a flat surface with the black union on the right and the firing devices facing the user. The quick-disconnecting unions are engaged by sliding the female union on the breathing tube over the male union on the canister and turning the collar of the female union to lock on the pins of the male union.

### 4. Donning the facepiece.

Once the canister is connected to the system, the facepiece is ready to be donned. To do this, first check to see that the lens is clean. Next, work the headband strap through the buckles to obtain maximum strap length. Grasping the two lower neck straps (marked NECK), one in each hand, raise the facepiece to the face, insert chin into the lower section and start the headband over the forehead. Slide the headband over the head and straighten straps to lie flat. Adjust the facepiece for a comfortable fit in the following manner:

- a. Pull the tabs to tighten the two lower NECK straps until snug.
- b. Pull the tabs to tighten the two SIDE straps until snug.
- c. Using both hands, grasp the facepiece lens ring and hold the facepiece while moving the head to gain a comfortable fit. When proper fit is obtained, retighten first the lower NECK straps and then the SIDE straps. Any remaining slack can now be removed by tightening the FRONT strap.
- d. Check the fit by squeezing the inhalation tube while inhaling gently. The facepiece should collapse on the face if the seal is satisfactory. If the facepiece does not collapse, outside air is entering the facepiece and the facepiece must be readjusted to eliminate the leak.

- e. Turn the head fully to see that the breathing tubes will not kink nor unduly stretch for such head motion. If undue stretch occurs, readjust the breastplate and breathing-bag assembly higher on the chest by shortening the shoulder harness straps.

NOTE: At any time during adjustment of the facepiece, or during any other procedure after donning but prior to starting the canister, a finger or fingers may be inserted between the cheek and facepiece to permit breathing as needed.

#### 5. Starting the chemical canister.

The apparatus is now fully donned and the candle ready to be fired to start the chemical reaction as follows:

- a. Unsnap the flap covering the firing devices on the canister.
- b. Grasp a firing device cap and the locking device fastened to the cap. Squeeze the locking device and cap together to release the lock.
- c. Turn the cap 90° in a counterclockwise direction. This action will ignite the candle.
- d. After a period of approximately three minutes, repeat steps 'b' and 'c' on a second firing device.

Approximately 15 seconds after the first candle has been fired, the breathing bag will begin to inflate.

NOTE: Once a candle is started, localized heating of the canister is experienced. Hence, caution should be taken not to touch the metal surface of the canister.

#### 6. Operational check.

The apparatus can now be checked for operational safety as follows:

- a. Grasp the lower end of the left-hand inhalation tube tightly while inhaling gently. The facepiece must collapse against the face. If it

does not, either the facepiece is not adjusted properly or there is a leak in the upper part of the inhalation tube. Either condition is unsafe and must be corrected.

- b. After an inhalation, grasp and squeeze both the inhalation and exhalation hoses and depress the manual relief valve on the chin of the facepiece. Exhaled air should now pass through the relief valve. If it does not, the valve must be repaired or replaced.
- c. Continue to hold hoses and pressure relief valve in and start to inhale. The facepiece must collapse on the face. If either operation on the relief valve does not perform as described, the valve is not functioning properly and must be repaired or replaced.
- d. With the inhalation tube released, inhale deeply and then squeeze the lower end of the right-hand exhalation tube as exhalation is started. The exhaled air must be forced out around the facepiece seal. This checks the inhalation valve and insures that no leaks exist in the upper part of the exhalation tube.
- e. With the breathing bag inflated with air, squeeze off both breathing tubes and press hard on the breathing bag with forearms and elbows. If the breathing bag deflates, a leak exists and must be corrected.

NOTE: During use of the apparatus, more oxygen will be produced than will be used. If the excess does not automatically escape around the face seal and breathing becomes difficult with increased exhalation resistance, depress the pressure relief valve until comfortable respiration is obtained. The breathing bag should be inflated but not tight.

#### CANISTER CHANGE

At the end of a four-hour period, the driver and passenger will be required to change over to another four-hour canister. This can most easily be accomplished by setting the canister being used on a flat surface so that the quick-disconnecting unions and the firing devices are facing the user. The black union assembly should be on the right. Next, place the replacement canister on top of the used canister,

oriented in a position identical to the bottom canister. Inhale deeply and disengage the silver quick disconnect. Immediately engage this to the silver male quick disconnect of the top canister. Now, the black exhalation quick disconnect can be disengaged from the bottom canister and engaged with the top canister. Fire two candles in the top canister according to Part 5 of the Preparation-for-Use section.

### CANISTER MOUNTING

While riding on the vehicle, the four-hour canister is held in a special carrier fastened to the vehicle. For excursions away from the vehicle, the four-hour canister is removed from the vehicle and carried on the special hip harness. The canister is transferred from the vehicle as follows:

1. Grasp the canister handle with the left hand and lift the canister away from the vehicle.
2. Insert the metal tab on the bottom of the canister into the notch provided on the bottom of the hip harness carrier.
3. Pull the top of the canister in against the hip harness carrier and insert the handle into the latch at the top of the carrier. When properly inserted, the handle will lock between the latch and the two metal tabs onto which the handle is fastened.

In order to remove the canister from the hip harness and place it back on the vehicle, the following procedure is used:

1. Grasp the canister handle firmly with the left hand and pull it out of the latch. This operation will free the canister and enable it to be lifted out of the bottom notch on the carrier and placed back on the vehicle.

### MAINTENANCE

The following are considered minimum maintenance procedures:

1. Cleaning

The apparatus should be cleaned after each use. Use a spanner wrench (Part No. 16726) to loosen

the breathing tube coupling nuts. Use Cleaner-Sanitizer (MSA Part No. 34377, or equal) as the cleaning agent. Proceed as follows:

- a. Dissolve one package (1 ounce) of Cleaner-Sanitizer in one gallon of fresh water at about 120 degrees F. (Mild soap and water may be used for cleaning but with reduced sanitizing effect.) While washing, hold facepiece in a position that will prevent cleaning solution from entering the valve body.
- b. Remove the valve cap, using a wrench (Part No. 455027) and disassemble the diaphragm. Remove the inhalation and exhalation check valves.
- c. Using a soft brush, clean cloth a sponge, thoroughly wash the diaphragm parts, facepiece and breathing tubes.
- d. Thoroughly rinse in clean, warm water and allow to air dry. To reduce drying time, wipe off excess water and then air dry.

## 2. Periodic Inspection

Periodic inspection must be aimed at locating the effects of age or weakness before operating problems develop. If there is any doubt as to serviceability of a particular item, repair or replace it. A complete inspection (Reference Table 1-1) is to be performed every three months when use is light, or even with no service use. When the apparatus is used frequently, inspection should be given every 1 1/2 months.

## 3. Inspection Procedure

Periodic inspections are to be performed as outlined in Table 1-1.

## 4. Operational Check

Once each calendar year, the apparatus should be functionally operated to insure serviceability of both unit and canister.

TABLE 1-1 INSPECTION

Point of Inspection	Method	Check For	Corrective Action
Facepiece	Visual	Holes, tears, or breaks in mask, stretched or torn straps, damaged buckles, loose clamp, or aged rubber. When applicable, damaged or missing microphones and adapters.	Tighten clamp or replace straps, facepiece, or microphone and adapters.
Lens	Visual	Scratches, cracks, loose clamps.	Tighten clamps (48444 only); replace lens.
Diaphragm assembly	Test	Hole or weakness by placing mask over face, grasp and squeeze both tubes, and exhale and inhale.	Snug retaining ring or valve cap firmly. Replace if pressure does not hold.
	Visual	Holes, tears, breaks, burned, or otherwise deteriorated material.	Replace.
Breathing tubes	Test	Holes or weakness by squeezing at hose clamp and blowing at coupling with some pressure and/or tears, cracks, holes or weakness in tubes by stretching and bending tubes all over.	Replace if pressure does not hold or there is doubt of serviceability.
Tube couplings	Test	Loose connections.	Tighten with spanner wrench provided.
Breathing valves, valve assembly	Visual	External damage or corrosion. (Damage only for plastic parts)	Replace.
	Test	Damage or leaks by placing mask over face, grasp and squeeze inhalation tube (L) and inhale; release inhalation tube, inhale, grasp and squeeze exhalation (R) tube and exhale.	Replace valve if pressure fails to hold.
Pressure relief valve	Visual	Corrosion or damage. Unscrew valve body for internal examination. (Do not lose the loose spring, 46407 valve assembly only.) Test according to paragraphs 4-17-2 and -3).	Replace.
Plunger assembly	Test	Sticking or binding by depressing several times.	Replace.
Timer	Test	Correct timing by setting at 60-minute mark and comparing rundown time with accurate clock. Timer must be accurate within $\pm 5$ minutes.	Replace. Tighten knob if loose.
Shoulder harness, waist strap	Visual	Frayed or torn material; crack in snap ring or buckle.	Replace.
Bail	Visual	Corroded threads; cracks or loose mounting nuts.	Tighten loose nuts or replace bail.

APPENDIX B

THE SILVER-ZINC BATTERY FOR THE 8-HOUR  
MISSION REQUIREMENTS

## APPENDIX B

## THE SILVER-ZINC BATTERY FOR THE 8-HOUR MISSION REQUIREMENTS

This section discusses the basis for the selection, the design and shortcomings of silver-zinc cells as the power supply for the MERV on the 8-hour mission originally proposed.

The battery specifications for the 8-hour mission were that it should be a rechargeable, 400-ampere-hour battery, with a minimum capability of 75 charge/discharge cycles and a minimum 1-year life in the charged condition. A normal recharge time of 30 hours was stated, with a target recharge time of 5 hours.

The battery selected for the MERV was a silver-zinc 24-cell unit designated as an LR 290 by Yardney Electric Corporation, which met the general requirements set forth above, and performed satisfactorily in the vehicle demonstrations. The LR 290's, however, would not meet the 75 charge/discharge cycle capability if defined as deep, or nearly complete discharges and, unless pulse charged, could not meet the 5-hour recharge target time. This criterion, although not emphasized in the contract Scope of Work, was obviously critical to the intended vehicle mission, and resulted ultimately in the vehicle being designed for a larger replacement battery.

DESIGN CONSIDERATIONS

Silver-zinc cells were selected for the battery on the basis of their power density. It was evident early in the design stage that both the battery weight and volume would have to be held to a minimum to meet the design criteria of the vehicle and to retain its initial concept as a highly maneuverable, fast-response, post-disaster unit.

Figure 1 compares the power density of the possible alternatives. Silver-zinc has about four times the storage capacity of the lead-acid and nickel-cadmium cells. A weight of 240 pounds was estimated for a suitable silver-zinc battery, which would place the weight of a lead-acid battery at about 960 pounds. Although expensive, when compared to lead-acid batteries, with a total design weight limited to 1500 pounds, the basis for selecting the silver-zinc becomes obvious.

A 36-volt system was selected for the MERV. This is a common low-voltage system and, at 1.5 volts per cell, the MERV battery would require only 24 cells.

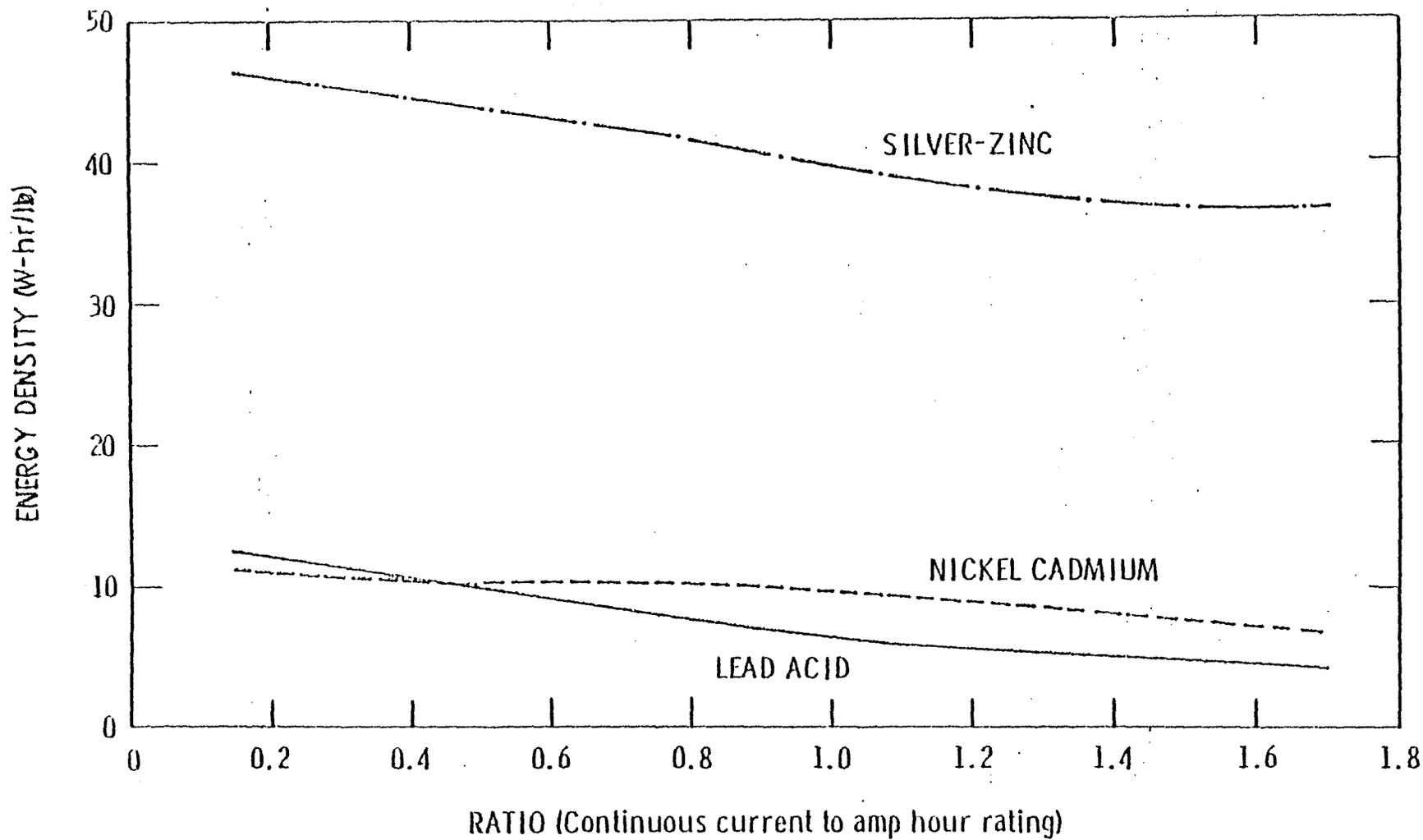
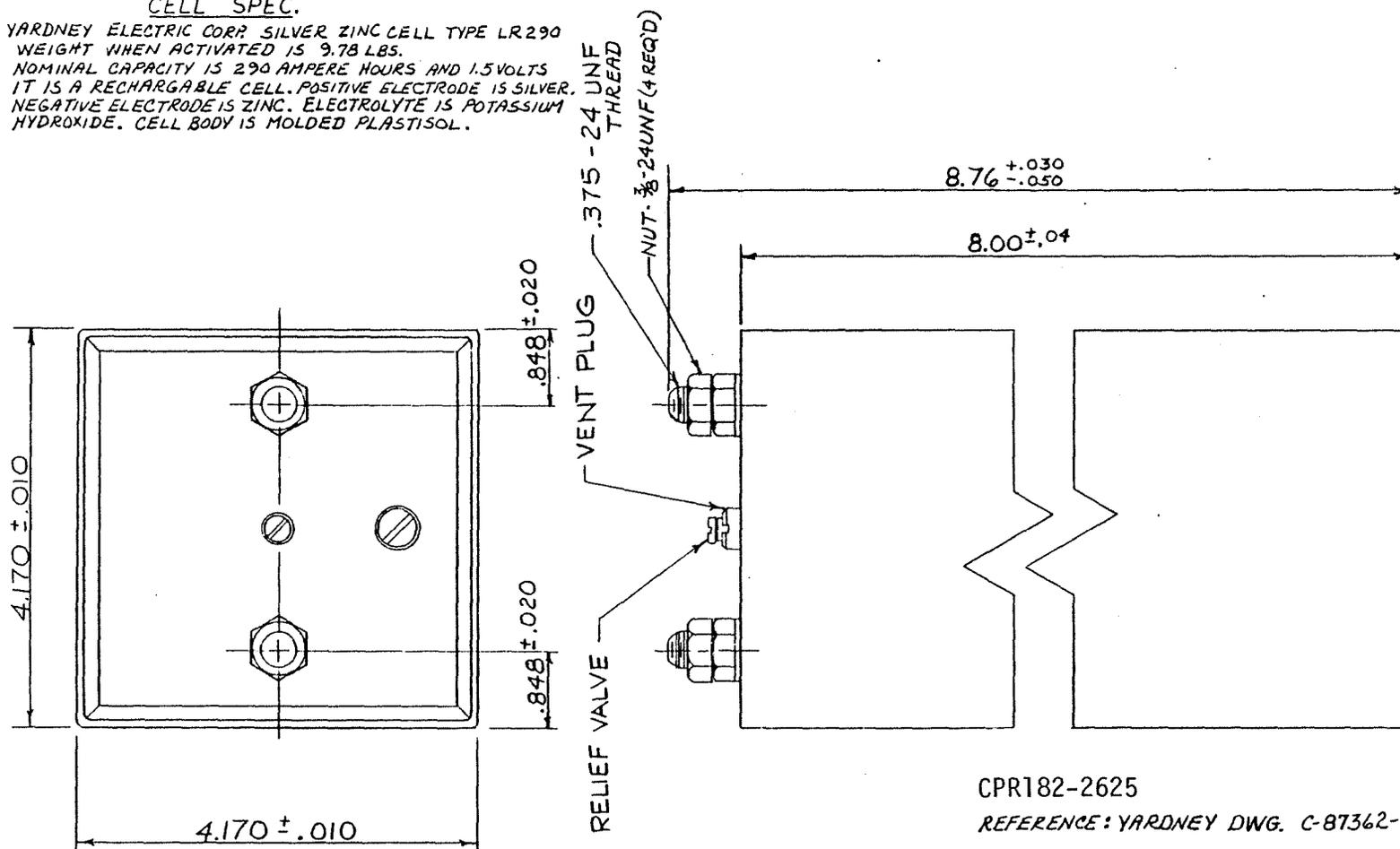


Figure 1 - Battery Capacity as a Function of Discharge Rate

CELL SPEC.

YARDNEY ELECTRIC CORP SILVER ZINC CELL TYPE LR290  
 WEIGHT WHEN ACTIVATED IS 9.78 LBS.  
 NOMINAL CAPACITY IS 290 AMPERE HOURS AND 1.5 VOLTS  
 IT IS A RECHARGABLE CELL. POSITIVE ELECTRODE IS SILVER.  
 NEGATIVE ELECTRODE IS ZINC. ELECTROLYTE IS POTASSIUM  
 HYDROXIDE. CELL BODY IS MOLDED PLASTISOL.



CPR182-2625

REFERENCE: YARDNEY DWG. C-87362-12973

Figure 2 - LR290 Cell Assembly

Silver-zinc cells are relatively new developments, but have adequate background to be considered reliable. These cells have seen significant use in the NASA space program and by the Navy. Cells of the capacity and type required for the program are considered to be well within the routine design capabilities of several manufacturers.

#### CELL DESIGN AND TESTING

The design of the individual cells is shown in Figure 2. The cell dimensions are 4.2 inches x 4.2 inches x 8.7 inches with an approximate weight of 10 pounds. These dimensions could accommodate an additional 75 ampere-hour capacity for the battery, if needed, with a weight penalty of about 1.5 pounds/cell.

The design rating of the cells was for an initial capability well in excess of 400 ampere-hours, but to level off after about 25 cycles to about 300 ampere-hours. At least 10 cycles were expected in excess of the required 368 ampere-hours under expected charge/discharge cycles, with considerably more cycles of at least 368 ampere-hours expected for the batteries under optimum conditions of discharge and charge.

Three cells were fabricated for testing. The formation cycles at Yardney Electric showed an initial capacity of 370 ampere-hours at a discharge rate of 40 amps, and 468 ampere-hours at a discharge rate of 60 amps on the second cycle. Recharging was conducted at a 10 amp rate.

At the request of the Bureau, the cells were further tested for 10 cycles with the following 8-hour discharge profile.

- First hour - 73 amperes
- Second to seventh hour - repeat cycles of 36 minutes at 37 amps, 9 minutes at 73 amps, and 15 minutes at 15 amps.
- Eighth hour - at 73 amperes

This discharge constitutes a 367.4 ampere-hour output. Charging was done at a 10 ampere rate to a cutoff voltage of 2.05.

After the fifth discharge cycle, all cells were drained at 37.0 amperes to a cutoff of 1.20 to determine the capacity as compared to the original formation capacity. The cells were monitored during the ninth discharge and tenth charge cycles to determine the maximum case temperature. Heating could lead to premature cell failure.

The results of the test are detailed in Appendix D. In summary, Yardney concluded that all three cells gave a 367.4 minimum ampere-hour output for the full ten cycles. Two cells were rated at the 367.4 ampere-hour output at a voltage cutoff of 1.335 and 1.338 volts respectively, or a total battery output (24 cells) of 32 volts. The third cell, in order to meet the 367.4 ampere-hour output, was drawn down to 1.01 voltage cutoff, which likely exceeded the minimum allowable voltage for operation of the motor and instrumentation packages. Although the 1.01 volt cutoff is objectionable as a reference voltage, it was pointed out by Yardney personnel that the rate of voltage decline at this point is rapid, and that the difference in time between an acceptable voltage of 1.30 and 1.01 would be small.

Table 1 compares the formation capacity of each cell with its capacity on the 5th and 10th discharge cycles.

TABLE 1 - COMPARISON OF TEST CELL CAPACITIES DURING TEST CYCLES

Cell Number	Output (Ampere-hours)		
	Formation to 1.1 V*	5th cycle to 1.2 V	10th cycle
1	473.5	455.5	367.4 (1.388 V)
2	473.0	448.8	367.4 (1.009 V)
3	500.0	454.4	367.4 (1.355 V)

\* Average of 2 cycles.

The data show good uniformity of cell performance.

The cell case temperature, which was recorded during the ninth discharge and tenth charge cycles (room temperature ambient) of the test program, is tabulated below:

TABLE 2 - TEMPERATURE OF TEST CELLS DURING CHARGE AND DISCHARGE

Cycle Number	Maximum Case Temperature (°F)	
	Initial	Final
9th discharge	80	121
10th charge	80	85

With proper spacing, cell temperature did not appear to be a problem.

An extrapolation of the test data to 75 and 100 cycles is shown in Figure 3. Based on the discharge-charge cycle employed in the test and considered a possible mission model by the Bureau, the LR290 cell would have only 68% of its required capacity at 75 cycles and 61% at 100 cycles. Although these results are unsatisfactory for the 8-hour mission, as defined for this contract, they would be adequate for 4-hour rescue missions presently being considered.

### BATTERY DESIGN

The design of the battery, which includes the configuration of the cells and the protective case, had to take into account a number of factors including available space, temperature effects, convenience of replacement and maintenance, and weight. Ultimately, special permissibility permits had to be obtained on the battery terminals, wiring and case to achieve the desired end result.

Configuration - The cell configuration in the battery can be made to suit space available in the vehicle. Some important points considered, however, were as follows:

- Overheating causes premature cell failure. At least two sides of the cell should be exposed to the air for heat dissipation. If clustering is necessary, air space should be provided between cells.
- The battery leads to the controller cannot be longer than 36 inches without additional fuzing.
- The battery design and placement within the vehicle should be convenient for easy replacement.

The final battery configuration consisted of a 4 x 6 cell arrangement, grouped as three sets of 2 x 4 cell units. A small gap was maintained between groups for heat dissipation. This arrangement resulted in a maximum lift of 80 lbs for replacing the battery, which should be reasonable for two men either in confined space or in the open.

Permission was obtained from the Bureau's Approval and Testing Branch for the use of bolted, rather than soldered intercell battery terminals. Recharging and replacement of the batteries requires the frequent breaking of connections between cells and/or cell groups, which would be impractical with soldered connections.

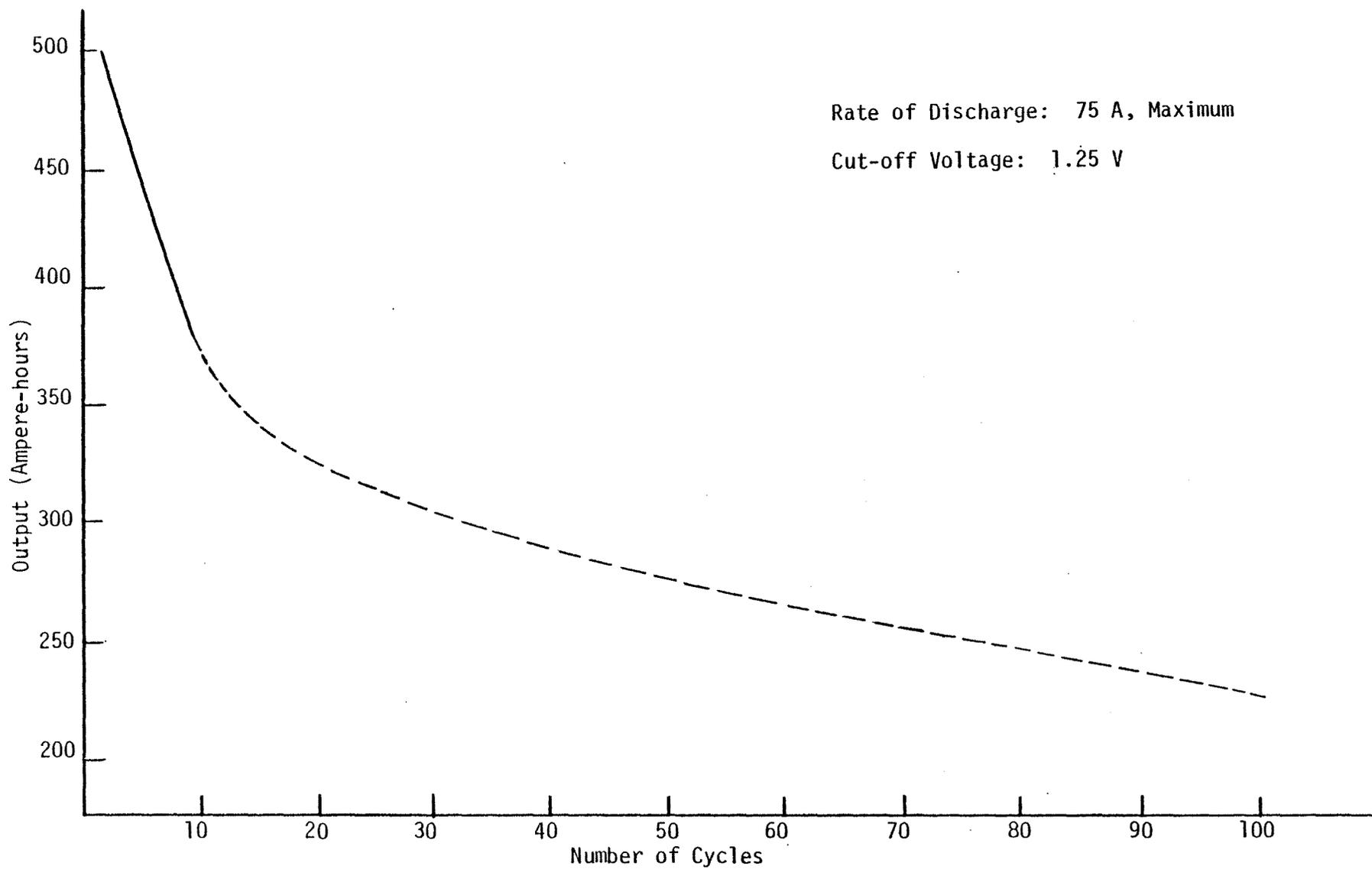


Figure 3 - LR 290-1: Expected Capacity vs. Number of Cycles

Permission was also obtained for the elimination of a running plug between the battery and the controller as a safety feature on the MERV. The controller wiring featured a manual reset which accomplished the same purpose.

Battery Case - Figures 4 and 5 show the design of the battery case and cover as fabricated for the vehicle. The battery case base was constructed of perforated 3/16 inch thick steel with 50 percent void space for weight savings. A fire-resistant plastic coating was provided for corrosion resistance. The battery case top was fabricated from solid 3/16 inch thick steel sheeting, coated inside and out with the same plastic material.

### CHARGER SPECIFICATIONS

The charger provided for the LR290 batteries was Yardney's SILVERCEL, Model VC 24-10. The charger is designed to charge adequately any number of silver-zinc cells from one to 24, with charging rates up to 10 amperes. It operates off a 105 to 120 volt A.C., single phase, 60 cycle power supply.

The charger uses a selenium transformer with full wave rectification. A variable transformer is used in the A.C. circuit for fine control of the D.C. output.

An automatic voltage cutoff stops the charge when the battery reaches a predetermined voltage. The cutoff voltage is a product of the individual cell voltage and the number of cells under charge, both of which can be selected on the charger control panel.

An indicator light indicates clearly the "on charge" or "off charge" status.

### PERFORMANCE AND RECOMMENDATIONS

The performance of the Yardney LR290 silver-zinc batteries met design specifications for the MERV unit with the exception of the desired 8-hour recharge capability.

In performance tests both on the surface and underground, the batteries met the power requirements of the situation and the total mission. In an extended in-mine test (much of it conducted with four and six people on the main unit and trailer) the battery delivered power for about three hours of estimated "full load" usage with an approximate 50% battery-power consumption. This would give an estimated full-load operating time of six hours for a designed mission equivalent

PARTS LIST			
ITEM NO.	PT. NO.	REQ'D.	DESCRIPTION
1			SHEET PERFORATED STEEL, HOLES $\frac{3}{16}$ " DIA. (328') STAGGERED $\frac{1}{2}$ " CTRS. 50% OPEN AREA.
2			ANGLE $2 \times 2 \times \frac{3}{16}$ CSTL COMM QUAL
3			BAR $\frac{3}{4} \times \frac{3}{16} \times 1 \frac{1}{2}$ CSTL AISI 1018 CF
4			ANGLE $1 \frac{1}{2} \times 1 \frac{1}{2} \times \frac{3}{16}$ CSTL
5			

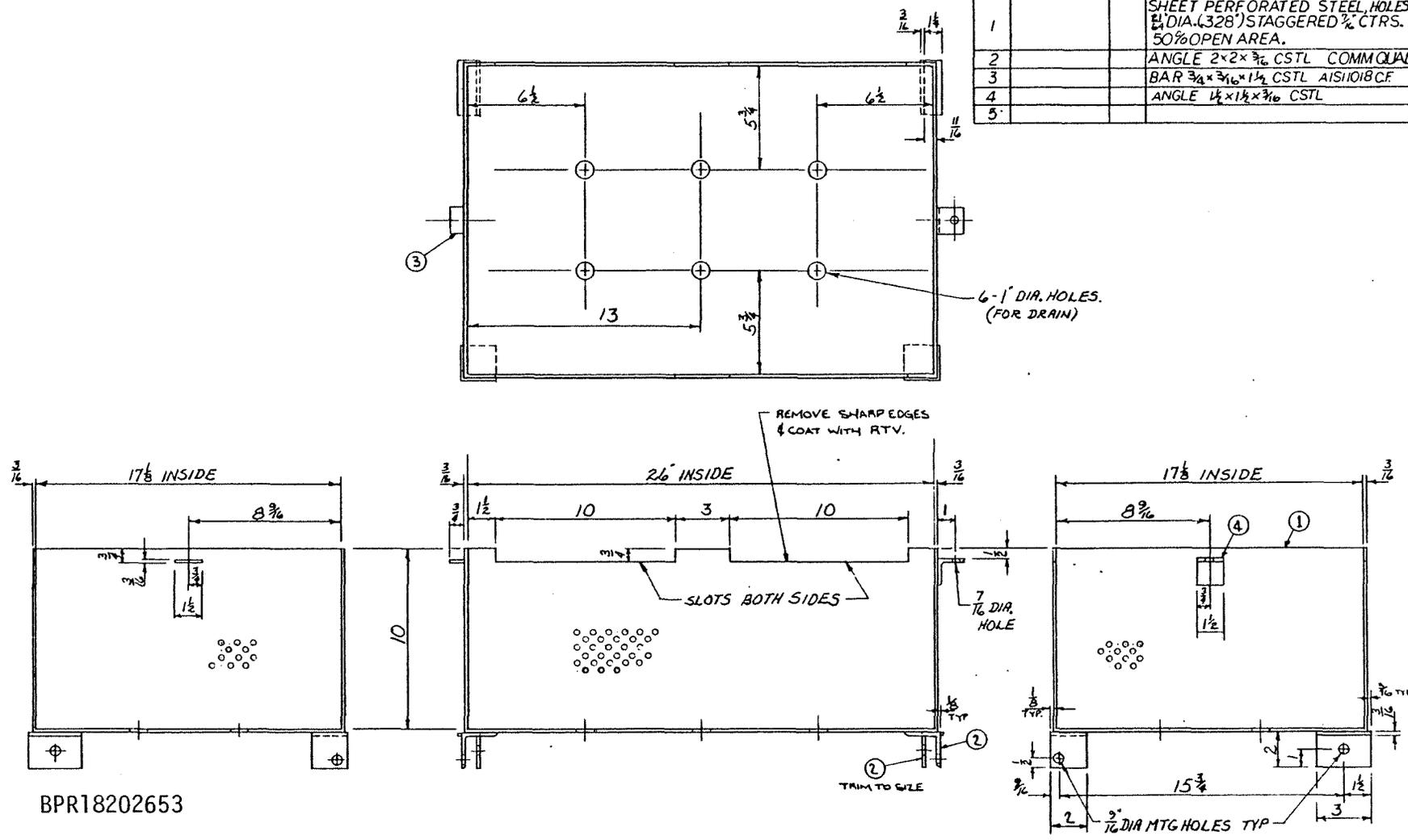


Figure 4 - Housing, MERV Battery

NOTES:  
 ALL WELDS  $\frac{3}{16}$ " CONTINUOUS.  
 HOUSING TO BE SANDBLASTED AND CLEANED,  
 THEN COATED WITH MICROSOL S-2003 (MICHIGAN  
 CHROME & CHEMICAL CO.) MINIMUM THICKNESS  
 .020". COLOR GRAY.  
 APPROX. WEIGHT=48 LBS



to five hours (two hours at full load, plus six hours at one-half load).

Adequate power was available for all maneuvering, with no apparent problems of overheating or malfunctioning.

The recharge capability of the LR290, however, is inadequate for the prescribed mission. Two batteries were to be supplied with the vehicle, each with sufficient power for an 8-hour mission. Under normal rescue-mission operation it was expected that a set of batteries would be operated for an approximate 8-hour period, be replaced by the second set, and be charged in the 8-hour interval during which the spare battery was being used.

The contract Scope of Work had specified that charging of the batteries should be accomplished in approximately 30 hours, or optimum time for long battery life, with a target fast charge-time of five hours. The LR290 batteries are not designed for fast charging, but are designed for producing the required 368 ampere-hour capacity with a minimum of weight. In order to have long cycle life, they must be charged over a 30- to 40-hour period. Obviously, this is unsuitable for the intended mission.

Several options were available in order to solve the battery problem:

- Install a battery designed for fast charging within the 8-hour period.
- Design a pulse charger suitable for charging the present batteries within the required 8 hours.
- Redefine the mission to a shorter span, use a lead-acid battery and, if necessary, redesign the vehicle to accommodate it.

Substitute a larger capacity battery - The first option would increase vehicle weight, since it requires a high-capacity, heavier battery which will accept the higher density charging rate and dissipate the heat without deterioration to any appreciable extent. Yardney Electric has developed data for an LR580 cell to meet these specifications. Table 3 compares its specifications with those of the LR290.

The design of a new silver-zinc battery would incorporate new technology to extend the expected battery life from the present one year to 3 or 4 years. NASA's Lewis Research Center has developed inorganic-based cell separators for

TABLE 3 - YARDNEY SILVERCELS - ESTIMATED PERFORMANCE CHARACTERISTICS

<u>Proposed Cell Type</u>	<u>LR290</u>	<u>LR580</u>
Initial capacity	470 AH	740 AH
Capacity - Cycle 10	370 AH	580 AH
Capacity - Cycle 75	290 AH	370 AH
Charge rate	17 amps	46 amps
Capacity - required output each cycle	370 AH	370 AH
Cell height (overall)	8.7 in.	12.0 in.
Cell weight (estimate)	10 lbs	15 lbs
Activation time	72 hours	72 hours
Estimated weight (24 cells)	240 lbs	360 lbs

silver-zinc cells that reportedly give additional wet life and cycle life. A production line for the new separators has been established by NASA at Yardney Electric Company, and the separators can be made available to the Bureau.

Design of a pulse charger - The second option, the design of a pulse charger for the present LR290's, also has merit. The feasibility of this option was investigated by Ocean Energy, Inc., of Blairsville, Pennsylvania. They investigated the following three charging methods to meet the contract goals:

- Fast D.C. charge
- Pulse charge
- A.C. charge

The complete report by Ocean Energy is submitted as Appendix E.

In their report, Ocean Energy pointed out the problems of the fast D.C. charge technique in terms of the type of silver deposition resulting during the charge cycle and its effect on total charge capacity and cycle life. To meet our charging time requirements, a battery using the fast D.C. charge technique would require a new cell design. A cell meeting these requirements (designated as Yardney LR580) was discussed in option one.

Both pulse charging and A.C. charging methods, according to Ocean Energy, may meet our charge requirements with the present LR290 cells. Extremely high fast-charging densities tend to plate the silver in a crystalline dendritic form which

produces long whiskers. These whiskers may penetrate the cell separator, and thus abruptly eliminate the life of the battery due to internal short circuits. If the high rate charge is periodically terminated, the electrolyte redistributes in the cell, and the long whiskers are redeposited as a large number of small whiskers which do not readily penetrate the separator.

The pulse charging technique can minimize this effect. It periodically applies a high current pulse up to 200 milliamperes per square inch of plate area and allows at least a similar period for cell electrolyte equilization. The A.C. charge method has the general characteristics of the pulse charge, but employs a short discharge to help reduce long whisker growth.

Ocean Energy's study, and thus their conclusions, is based totally on data gathered from the literature and their experience. They recommend experimental studies in order to verify their conclusions; however, in particular reference to the LR290 cells, they conclude that either pulse or A.C. charging would be feasible.

Redefine the mission - The third option, redefining a shorter mission, would allow for use of the more economical lead-acid batteries. This option was selected. Our discussions with MESA rescue personnel had placed doubt on the 8-hour requirement for the rescue mission. A period of four hours appeared to be a more practical time consideration.

The 4-hour mission, using a lead-acid battery, would eliminate recharge problems, lengthen expected cell life, and significantly reduce battery costs. Silver-zinc cell costs are subject to highly fluctuating and rising silver costs, making the batteries a major item in the overall vehicle cost. Lead-acid batteries would likely be less than one-fifth the cost of similar performance silver-zinc batteries.

APPENDIX C

MINE EMERGENCY RESCUE VEHICLE  
MOBILITY PERFORMANCE ANALYSIS

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## MINE EMERGENCY RESCUE VEHICLE MOBILITY PERFORMANCE ANALYSIS

### INTRODUCTION

The MERV (mine emergency rescue vehicle) is a battery-powered, mine permissible, wheeled vehicle intended for mine rescue work. It transports and provides life support for a crew of two and carries instrumentation and tools. In addition, it is capable of towing a wheeled trailer which can transport injured personnel.

Major considerations in the design of the MERV were as follows:

- Permissibility
- Mobility
- Adaptation of available technology to reduce costs

This report is concerned only with the mobility aspects.

### GENERAL MOBILITY REQUIREMENTS

Due to its intended use, the MERV must be able to function effectively over a wide range of conditions. For example, it must be capable of operating both in high and low seam mines and maneuvering in limited spaces. It must be able to travel over ground with soil conditions ranging from dry and hard to soft, wet and muddy, as well as traverse without damage over obstacles such as rails, rubble, rocks and fallen timbers. And it must do all this with a minimum expenditure of battery energy in order to achieve a useful range and time duration.

### GENERAL DISCUSSION OF MOBILITY

The successful adaptation of a vehicle to an off-road environment depends not only on the vehicle characteristics, but also on the characteristics of the terrain over which it must travel. Two general types of terrain characteristics influence mobility performance.

- The mechanical properties of the soil which relate to the stress-strain relationship existing between soil and vehicle, both in the vertical and horizontal directions.
- The surface geometry of the terrain.

The vertical-deformation characteristics determine the ability of the vehicle to stay on or close to the surface (flotation), while the horizontal characteristics determine the ability of the vehicle to develop locomotion traction.

The surface geometry of the terrain affects mobility in that obstacles, such as boulders, crevices, fallen timbers or other debris, may prevent or at least hinder vehicle movement, and rough ground may impart unacceptable shock and vibration to the crew, vehicle structure and payload, and may also affect the ability of the vehicle to develop tractive effort (for example, by causing wheels to lift off the ground).

Therefore, to evaluate mobility performance, in addition to knowing the pertinent vehicle parameters such as size, form and weight, load distribution, size and form of the wheel contact areas, and power train characteristics, it is necessary to quantitatively describe the terrain characteristics that affect performance. Mathematical models expressing the physical and geometric relationships between the vehicle and soil can then be used either to evaluate performance characteristics or, given a desired level of performance, to select vehicle design criteria. Results of laboratory and field tests can also be utilized to confirm calculated analytical treatment.

The mobility performance characteristics that are of most significance to MERV are:

- Performance in deformable soils including tractive effort, drawbar pull, motion resistance, and wheel sinkage.
- Obstacle capability (boulders, timbers, hang-up).
- Maneuverability (steering and off-tracking).
- Stability (lateral and longitudinal).
- Torque, power, and energy requirements.

Features such as ride, acceleration, and dynamic stability characteristics are of minor importance in this application due to the low speed requirements.

### DEFORMABLE SOIL CONSIDERATIONS

Good performance in deformable soil is characterized by low wheel sinkage which prevents the vehicle from bottoming out, reduces motion resistance, and permits high tractive effort to be developed.

A low value of motion resistance is extremely important, particularly for MERV, for the following reasons:

- The energy required for locomotion is directly proportional to motion resistance. Therefore, battery size and weight requirements are seriously affected. Drive train continuous power requirements are also directly affected.
- The drawbar pull (DP), or net tractive effort, a vehicle can develop is one of the most important single measures of its mobility capability. This value is a measure of the vehicle's ability to do useful work, such as negotiate grades and obstacles and low loads, and is equal to the gross tractive effort the vehicle can develop minus the motion resistance it must overcome.

Motion resistance can be expressed by the following equation:

$$R = R_s + R_f + R_g$$

where

R	=	Total motion resistance
R <sub>s</sub>	=	Resistance due to soil deformation
R <sub>f</sub>	=	Resistance due to tire flexure
R <sub>g</sub>	=	Resistance due to grades

The value R<sub>g</sub> is dependent only on the grade and vehicle weight. R<sub>s</sub> is a function of the ground pressure, the size and form of the tire contact area, and the characteristics of the soil. R<sub>f</sub> is a function of the construction of the tire and its deformation characteristics.

Regarding this aspect of performance, motion resistance can be reduced by:

- Reducing vehicle weight.
- Increasing the ground contact area. This can be achieved by increasing the number, diameter, or width of the tires, decreasing the tire pressure, or using softer tires.

The maximum tractive effort a vehicle can develop can be expressed by

$$H = cA + W \tan \phi$$

where: H = Gross tractive effort  
 A = Ground contact area  
 W = Weight or wheel loading  
 c = Soil cohesion  
 $\phi$  = Soil angle of friction

and the drawbar pull can be expressed by

$$DP = H - R$$

Since an increase in vehicle weight causes the motion resistance R to increase at a rate greater than the gross tractive effort H, it is apparent that an increase in ground contact area is the logical means for improving drawbar pull performance; i.e., minimizing R maximizes DP.

### OBSTACLE PERFORMANCE

The discrete obstacle performance capability of a vehicle is limited in two ways:

- Interference with the ground or obstacle by some part of the vehicle other than the wheels (hang-up).
- Insufficient traction to overcome the obstacle.

The first case depends on vehicle geometry, and is a function of the vehicle ground clearance and angles of approach,

departure, and break. The ground clearance and angles of approach and departure should be as large as possible, and the break angles (between the wheels) as small as possible.

For the second case, assuming the vehicle powerplant is not torque-limited, the obstacle capability (e.g., climbing over fallen timbers, rocks, or logs, or crossing ditches) will depend primarily on the drawbar pull the wheels can develop, the location of the center of gravity, the wheel diameter, and the wheelbase of the vehicle. Normally, the larger the wheel diameter and the wheelbase, the better the performance.

Secondary considerations are the wheel and suspension deflection characteristics. Generally, soft tires will improve obstacle performance by increasing traction capability.

### MANEUVERABILITY

Maneuverability is a particularly important aspect of performance to be considered in the case of MERV, due to the limited spaces in which the vehicle must operate. Many types of steering are possible, and all have been used with varying degrees of success. These include:

- Ackermann-type steering
- Wagon steering (or fifth wheel)
- Frame articulation steering
- Skid or scuff steering.

For the MERV, only skid steering is considered to be appropriate.

#### Skid or Scuff Steering

This type of steering is common on tracked vehicles; however, its use on wheeled vehicles is only occasional, confined largely to a few experimental vehicles, some short-coupled agricultural and construction tractors, and to a wide group of recreational vehicles. In this type of steering, the change in heading is accomplished by changing the relative speeds of the wheels on the two sides of the vehicle, thereby developing turning moments to overcome resisting forces. Given sufficient power, it is possible to pivot in place.

Considerable lateral and longitudinal sliding takes place, resulting in high power losses, loss of traction, and a high expenditure of energy. To minimize these losses, it is

necessary to keep the wheelbase-to-tread ratio as low as practicable. Most current Army tanks have ratios on the order of 1.4 - 1.6 to 1. In the case of wheeled vehicles, even lower ratios have been recommended. This usually results in a low aspect ratio vehicle, -- one with a stubby appearance.

An important advantage of this type of steering is that, since the wheels do not have to pivot relative to the vehicle centerline, encroachment into the vehicle body is minimized.

### Off-Tracking

Another aspect of maneuverability that must be considered is the off-tracking between wheels during a turn. Since the turning radius of each wheel is usually different, the width of the path required to permit a turn -- say from one narrow tunnel to another -- is an important consideration, even more so when a trailer is being pulled.

### STABILITY

In the design of a vehicle, both static and dynamic stability characteristics are normally considered. MERV will have a speed of only 7 mph maximum; consequently, detailed dynamic considerations, such as stability during a turn and overturning moments generated by acceleration or braking, can be safely ignored.

As to static stability, which includes pitch and roll, these factors are easily treated. The general requirement for static stability is that the vehicle can safely operate, either in the lateral or longitudinal direction, on the maximum slopes expected to be encountered, and must not overturn when one side of the vehicle is negotiating an obstacle.

MERV's stability requirements can be satisfied by a low center of gravity and relatively large wheelbase and tread dimensions.

### TORQUE, POWER, AND ENERGY REQUIREMENTS

Torque, power and energy requirements for locomotion can be determined in detail from the requirements of the RFP, the results of the performance analyses discussed above, and the establishment of a specific mission profile. For an off-road vehicle, the maximum continuous duty steady-state torque is usually established by the maximum gradeability requirement

(45% for MERV). The maximum steady-state power can be established either by a requirement to climb the maximum grade at a certain minimum speed, or by the requirement to attain maximum speed (7 mph) over some specified soil condition. The intermittent torque value will probably be established by the worst obstacle the vehicle must negotiate (12-inch log).

Although the bulk of the energy required for locomotion is to overcome motion resistance, allowance for obstacle negotiation, travel over rough or uneven terrain, and for maneuvering, must also be made. Since it is impossible to define detailed duty cycles for these occurrences, it is usually necessary to make allotments based on past experience.

### TECHNICAL APPROACH

The major consideration early in the program was the selection of the size and number of tires for MERV.

Therefore, performance analyses relating to the mobility characteristics previously discussed were conducted using analytical techniques and procedures developed by the U. S. Army Tank - Automotive Command Land Locomotion Laboratory for the evaluation of military vehicles.

Since the weight of the MERV and the terrain characteristics over which it would be expected to operate were unknown, it was necessary to conduct the studies on a parametric basis.

However, based on practical considerations and restraints it was possible to limit the scope to a reasonable range. For example, the BuMines RFP postulated the following design and performance requirements affecting MERV mobility performance:

- Length, maximum - 100 inches, not including trailer
- Width, maximum - 56 inches
- Ground clearance, minimum - 5 inches
- Grades - Operate on 45%
- Speed - 7 mph

- Turn radius - turn in own length
- Power time range - 2 hours full load,  
6 hours half load
- Obstacle - cross 12-inch diameter
- Soft ground - travel over soft muddy mine floors
- Weight, empty - 1500 lbs (not including trailer).

Other implicit constraints were the adaptation of an existing vehicle rather than a ground-up design, and the use of available tires.

In addition, visits early in the program to both a low seam coal mine and a deep shaft ore mine served to indicate the range of soil conditions in which the MERV might operate: hard and dry to extremely wet and soft.

Eighteen (18) soils of known characteristics were originally selected in which to evaluate MERV soft soil mobility performance. These were soon reduced to eleven (11) specific soils representing two general types: dry, sandy soils and moist loamy soils. The other seven (7) soils have characteristics lying between these two types and were not considered important to the study. The selected soils are tabulated in Table 1, with their pertinent characteristics. The values of 'c' and ' $\phi$ ' are as described previously. The higher the value of either, the greater the tractive effort the vehicle can develop.

The values 'K' and 'n' are related to the bearing strength of the soil. The higher their value, the more firm the soil, with less sinkage taking place at a given ground pressure. Simply stated, the relationship between contact area ground pressure and sinkage can be expressed as follows:

$$p = Kz^n \quad \text{where } p = \text{average ground pressure (psi)}$$

$$\text{and } z = \text{sinkage (inches).}$$

In the case of the loamy soils, the moisture content increases from Soil (13) to Soil (18). Note how the strength parameters decrease with increasing moisture.

TABLE 1 - SOIL TYPE CHARACTERISTICS

<u>Soil Number</u>	<u>Consistency - K</u>	<u>Type</u>	<u>Cohesion - c</u>	<u>Angle of Friction <math>\phi</math></u>	<u>n</u>
8	3.0	Dry, Sandy	0 psi	29.0°	1.00
9	8.0	Dry, Sandy	0	29.0°	1.00
10	12.0	Dry, Sandy	0	29.0°	1.00
11	15.0	Dry, Sandy	0	29.0°	1.00
12	22.0	Dry, Sandy	0	29.0	1.00
13	8.6	Moist, Loamy	1.8 psi	29.2°	0.53
14	6.7	Moist, Loamy	1.8	27.5°	0.50
15	5.5	Moist, Loamy	1.8	25.5°	0.47
16	4.4	Moist, Loamy	1.8	23.5°	0.43
17	3.2	Moist, Loamy	1.0	21.5°	0.39
18	2.1	Moist, Loamy	0.8	19.7°	0.35

As a point of reference, it is estimated that the worst condition noted in the coal mine previously mentioned is probably equivalent (from the standpoint of flotation) to Soil (17) or (18).

With respect to the dry, sandy soils, Soil (8) is equivalent to an uncompacted beach sand.

Tires considered were limited to the low-pressure type commonly used on recreational and other "all terrain" vehicles; and, based on the previously mentioned constraints, it was evident that only 6- and 8-wheeled vehicles should be considered in this application.

Soft soil analyses were conducted on a per-wheel basis over a range of possible wheel loadings and the results extrapolated to a given vehicle configuration. Analyses of skid steering and obstacle-climbing capability, including torque requirements, were also conducted.

Results of these analyses were forwarded on a regular basis during the course of the program and were included in MSA monthly reports to the Bureau of Mines. Therefore, they will only be summarized here.

## RESULTS

### SOFT SOIL PERFORMANCE

Dimensional and geometric constraints for MERV limited consideration to the following tires:

- 21 x 11 - 8
- 23 x 19.5 - 12
- 26 x 12 - 12 (4 ply)
- 26 x 12 - 12 (2 ply)

Two tires were considered for the MERV trailer:

- 12 x 11 - 6
- 21 x 12 - 8

Some major conclusions drawn were as follows:

From the point of view of soft soil mobility, the optimum tire should have the following characteristics:

- A large diameter

- A large footprint, achieved by low air pressure and a flexible tire carcass. In other words, a tire should be operated with the largest deflection permissible at a given load within the life and endurance restrictions of the tire.

The above are illustrated in the graphs of Figures 1 through 3. In Figure 1, it can be seen that the 26 x 12 - 12 tire is superior in a soft soil to the 21 x 11 - 8 tire, particularly at higher wheel loads. This in spite of the fact that calculations for the smaller tire assumed a much higher deflection than for the larger tire. (This would probably result in a lower life expectancy for the smaller tire.) The differences between the two would be larger if equal deflection characteristics were assumed. This can be deduced from Figure 2, where calculations made for the 26 x 12 - 12 tire at three different deflections are shown. This also shows the effect of a "softer" tire construction - 2 ply versus 4 ply.

Figures 1 and 2 also show the effect of wheel load on motion resistance. It can be seen that the resistance-to-wheel-load ratio climbs rapidly as load increases. Although this is much more pronounced for the very soft loam soil (Soil 18), the rate of increase is also appreciable for the sandy soil (Soil 8). Since the energy the power source must supply is directly proportional to the resistance, this demonstrates the importance of keeping vehicle weight as low as possible and, to a lesser extent, keeping wheel loadings equal.

With regard to uneven wheel loading, the importance of this factor is dependent on the magnitude of the inequality and type of soil in which the vehicle operates. As an example, comparing a 6-wheel vehicle of axle loadings of 23.3%, 33.3% and 43.3% with one of equal loading, the deterioration in performance due to unequal loading ranged from a fraction of a percent in very firm soils to about 7% in a very soft soil.

Figure 3 compares the performance of two candidate MERV trailer tires over the entire range of both soil classes considered. Note the large improvement in performance in going from the original small tire to the present large tire.

#### OBSTACLE PERFORMANCE

Results of the obstacle performance analysis can be summarized as follows:

- Given the same coefficient of friction between tires and ground, vehicles with large diameter tires are capable of

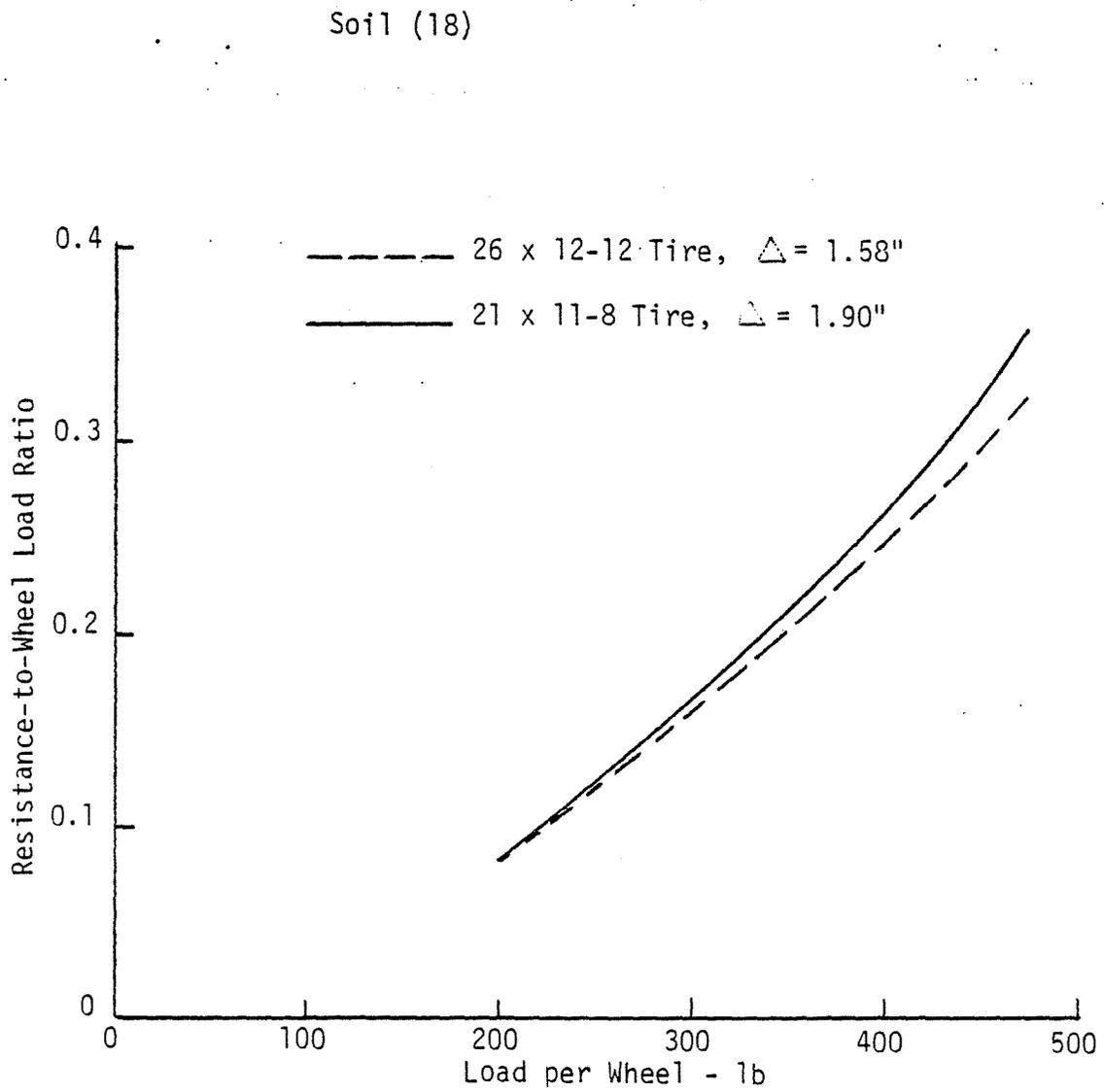


Figure 1 - Comparison of Two Candidate Tires in Soft Soil

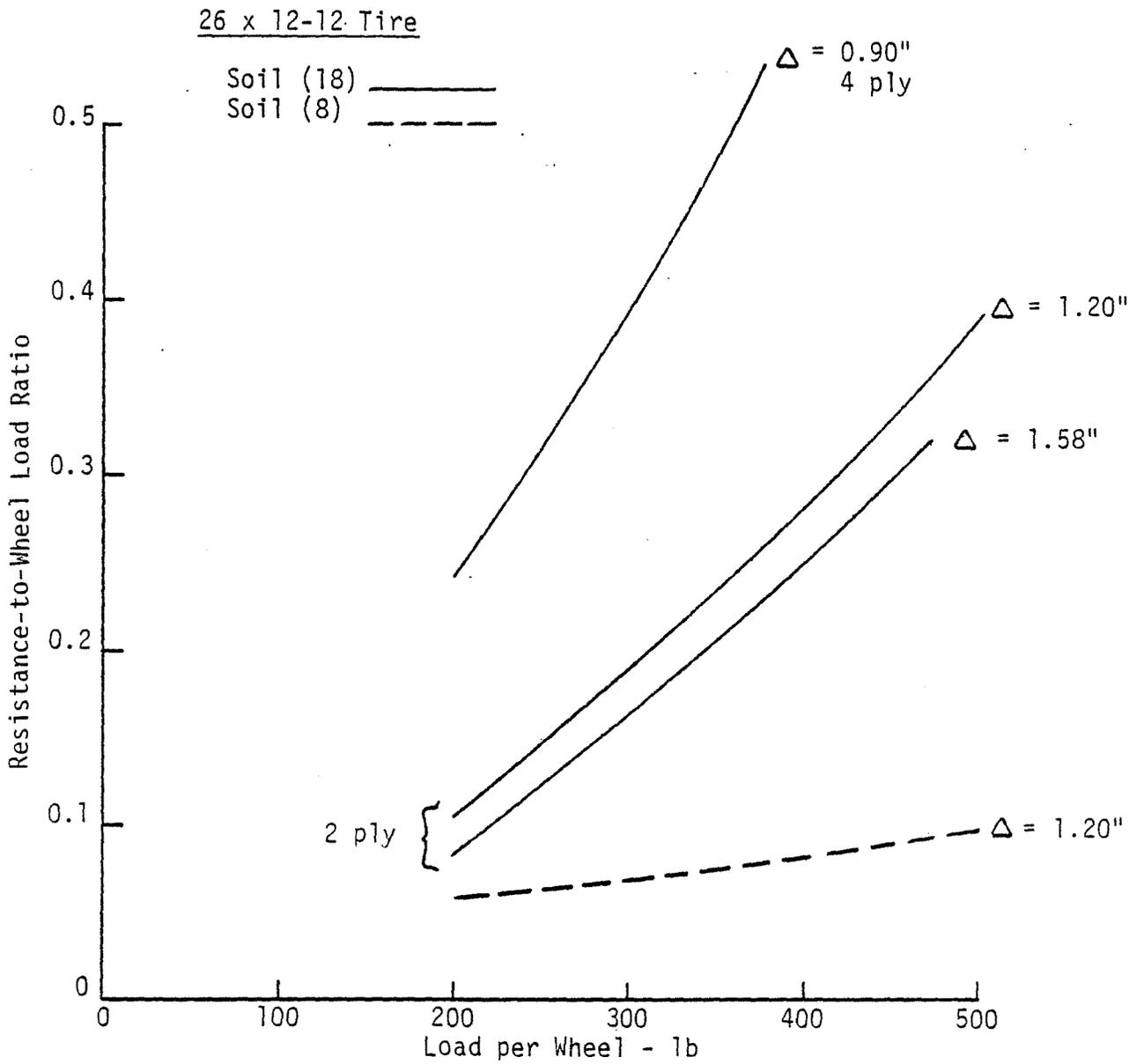


Figure 2 - Effect of Tire Deflection on Motion Resistance

Load per Tire = 300 lb

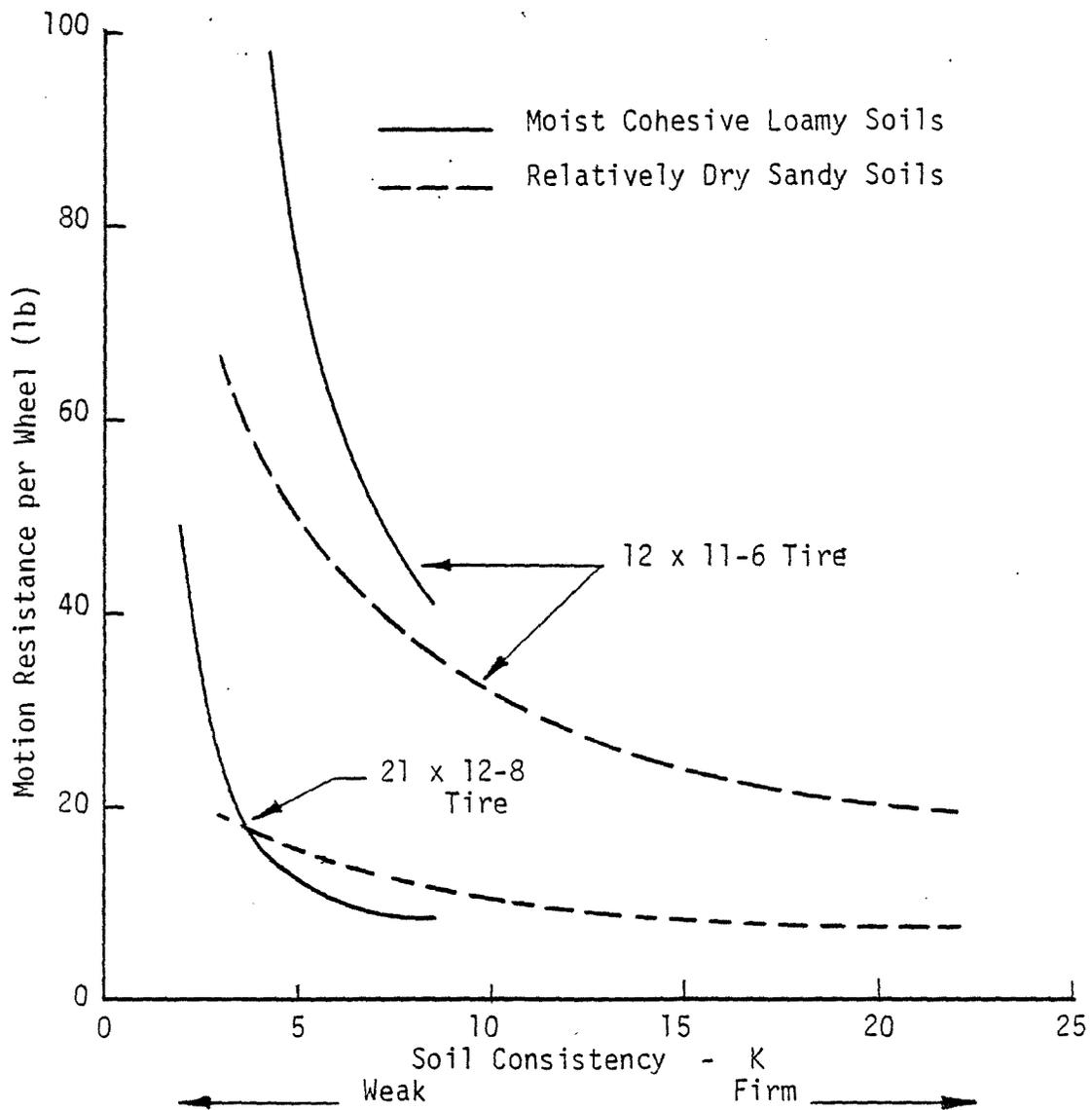


Figure 3 - Comparison of Tires for MERV Trailer

negotiating higher obstacles than vehicles with smaller tires.

- To surmount an obstacle of a given height, small diameter tires require more force (equivalent to motor torque) than large diameter tires.
- The obstacle height a vehicle can negotiate is partly a function of the net tractive (drawbar pull) that the vehicle can develop. This favors tires which develop minimum motion resistance.
- The vehicle wheelbase should be as large (distance from front wheel axle to rear wheel axle) as practicable.

### SKID STEERING

The most significant point with respect to skid steering is that the ratio of the vehicle wheelbase to the tread width should be kept small, to permit steering forces to be kept small.

Other factors influencing skid steering ability are the tractive effort the vehicle can develop and the motion resistance at the tire-ground interface that the vehicle must overcome. Again, this favors tires with large ground contact areas, resulting in minimum tire sinkage.

### STABILITY

As a minimum, the MERV should be capable of operating in any direction on the 45% slope specified in the BuMines RFP. Since in all cases the vehicle wheelbase will be greater than the tread, the critical requirement is for sufficient lateral (roll) stability. This is not a stringent requirement and can easily be met due to the low silhouette required to enable the vehicle to operate in low seams.

### ENERGY, POWER AND TORQUE

Battery energy locomotion requirements are directly proportional to the motion resistance the vehicle must overcome and the distance it must travel. It can be easily calculated that for each pound of resistance, 2 watt-hours of energy are dissipated at the ground for each mile of travel. To calculate

battery energy requirements, the efficiency of the complete drive system must be taken into account (motor controls, motor and speed reduction).

Road load power (that required at the wheels) is directly proportional to both motion resistance and speed and can be calculated as follows:

$$HP_{r1} = \frac{(R)(V)}{375}$$

where  $R$  = motion resistance (lb)

and  $V$  = vehicle speed (mph).

Therefore, to maintain the RFP requirement of 7 mph on level ground, one horsepower is required at the road to overcome each 53.6 lbs of resistance. To calculate motor output power, the efficiency of the speed reduction must be considered.

As mentioned previously, the peak torque output is usually established by the obstacle negotiation requirement, and is usually required only for a short period of time: 5 to 15 seconds. High torque outputs of longer duration are required to climb grades; in this case, 45%. These requirements can be determined from the following:

$$(T_m) (\lambda) (\eta) = (R)(r)$$

where  $T_m$  = motion torque output

$\lambda$  = speed reduction ratio

$\eta$  = efficiency of the speed reduction

$R$  = vehicle motion resistance

and  $r$  = tire rolling radius.

### CONFIGURATION SELECTION

Early in the program, three configurations considered to be applicable for MERV were established, as follows:

<u>Configuration No.</u>	<u>1</u>	<u>2</u>	<u>3</u>
No. of wheels	6	6	8
Overall Length	100 in.	100 in.	107 in.
Overall Width	56 in.	56 in.	56 in.
Tire Size	21 x 11 - 8	26 x 12 - 12	21 x 11 - 8
Tread Width	44.5 in.	43.3 in.	44.5 in.
Axle Spacing	28 in.	34 in.	25 in.
Wheelbase	56 in.	68 in.	75 in.

These were analyzed for a range of gross vehicle weights from 1750 lbs to 2200 lbs, and for various wheel load variations.

None of the above configurations was superior in all respects. For example, it was concluded that the 8-wheel vehicle was superior from the viewpoint of soft soil performance, the 6-wheel vehicle with 26 x 12 - 12 tires was best with respect to obstacle negotiation, and 6-wheel configuration with 21 x 11 - 8 tires was best in regard to skid steering.

Overall, it was decided that the 8-wheel configuration probably represented the best compromise. However, it should be noted that the analyses compared all configurations at equal weights, whereas the empty weight of the 8-wheel vehicle in all probability would be heavier than the 6 x 6's. In addition, the 8-wheel configuration violated the maximum length constraint of 100 inches. (This was not considered necessarily important although maneuvering capability would suffer somewhat.)

Another major factor that led to a re-evaluation of the configuration selection was the fact that the 26 x 12 - 12 tire considered in the above analysis was of a 4-ply, relatively stiff construction, resulting in high motion resistance in soft soils. It was then learned that this tire could be made available in a flexible, 2-ply construction. New analyses based on this tire were conducted, leading to the conclusion that a 6-wheel vehicle with 26 x 12 - 12, 2-ply tires and an axle spacing of 30 inches was the optimum configuration for MERV application.

## MERV DISCUSSION

GENERAL DESCRIPTION

The general characteristics of the MERV are as follows:

Weight	1850 lbs (w/o crew)
Length	100 inches
Width	56 inches
Height	33 inches (nominal)
Wheelbase	60 inches
Tread	43.3 inches
Ground Clearance	6 inches
Angle of Approach	56°
Angle of Departure	64° (w/o trailer hitch)
Angle of Departure	58° (w/trailer hitch)

The MERV trailer is equipped with two 21 x 12 - 8 tires, resulting in a ground clearance of more than 12 inches. Empty weight of the trailer is 250 lbs.

POWER TRAIN

The basic power train of the vehicle consists of a 36-volt (nominal) silver-zinc battery pack, a DC motor rated at 3 HP @ 1750 rpm, an SCR chopper control, and a transmission and chain drive to all six wheels. Motor performance curves are shown in Figure 4.

Early in the program, it had been planned to use an overall speed reduction of 22.9 from motor to wheels. Analyses of obstacle negotiation capability indicated that, since the drive motor was current limited, torque output at the wheels would not be sufficient to permit the vehicle's full capability to be utilized. On this basis, the reduction was increased to 28.9 in forward (34.4 in reverse). This provides the MERV with excellent obstacle-crossing and grade-climbing capability, although maximum speed is compromised somewhat.

36 Volts

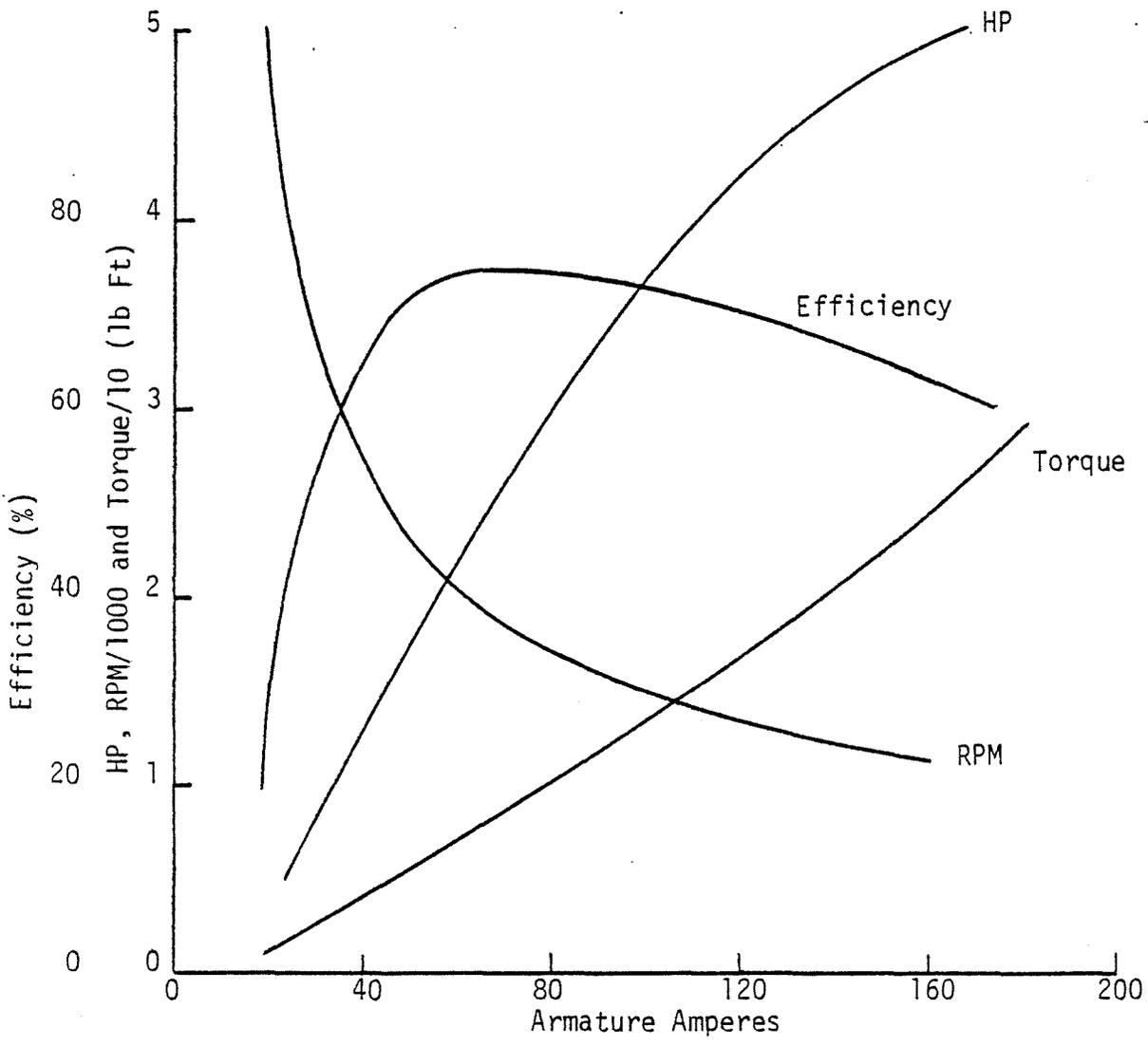


Figure 4 - MERV Drive Motor Characteristics (Calculated)

## SOFT SOIL PERFORMANCE

After the baseline MERV configuration had been established, soft soil analyses were performed for the range of soils previously considered. Figures 5 and 6 show the vehicle motion resistance in moist loam and dry sandy soils, respectively. Equal wheel loadings and a 5 psi inflation pressure were assumed. If necessary, performance in soft soils could be improved by operating the tires at a lower pressure. The effect of a loaded trailer is also included in these graphs.

Energy requirements for traversing level ground of known characteristics can be determined from these graphs in the manner previously described.

Figure 7 shows the expected drawbar-pull capability of MERV, with and without the trailer, in the soil types investigated. As discussed previously, drawbar pull is an important measure of vehicle mobility in that it is related to the capability of the vehicle to climb grades, tow loads and to accelerate. For example, a drawbar pull-to-weight ratio of 0.5 means that the vehicle can climb a 50% grade in that soil condition. Considering the relatively weak soils used in these analyses, MERV has excellent performance in this respect.

A noteworthy point relative to this graph is the fact that over most of the range of soil consistencies, the drawbar pull-to-weight ratio is higher in the moist loam soils than in the dry sandy soils. This in spite of the fact that the motion resistance results previously presented showed that resistance was usually much higher in the loam soils. This is due to the fact that the values of cohesion,  $c$ , are significant in the case of the loam soils; while, in the case of the sandy soils, cohesion is virtually nonexistent. Thus, the vehicle can usually develop significantly higher tractive effort,  $H$ , in loam than in sand.

## MERV DEMONSTRATION TESTS

Two formal demonstration tests of the MERV were held to demonstrate compliance to the requirements of the BuMines RFP. Above-ground testing was conducted on June 14, 1973, at MSA's plant near Evans City, Pennsylvania. Coal-mine operation was demonstrated at Union Carbide Corporation's Fawn Mine near Saxonburg, Pennsylvania, on July 18, 1973.

Comments relative to the above-ground tests were transmitted previously and are attached to this report as Appendix

(Moist Cohesive Loamy Soils)

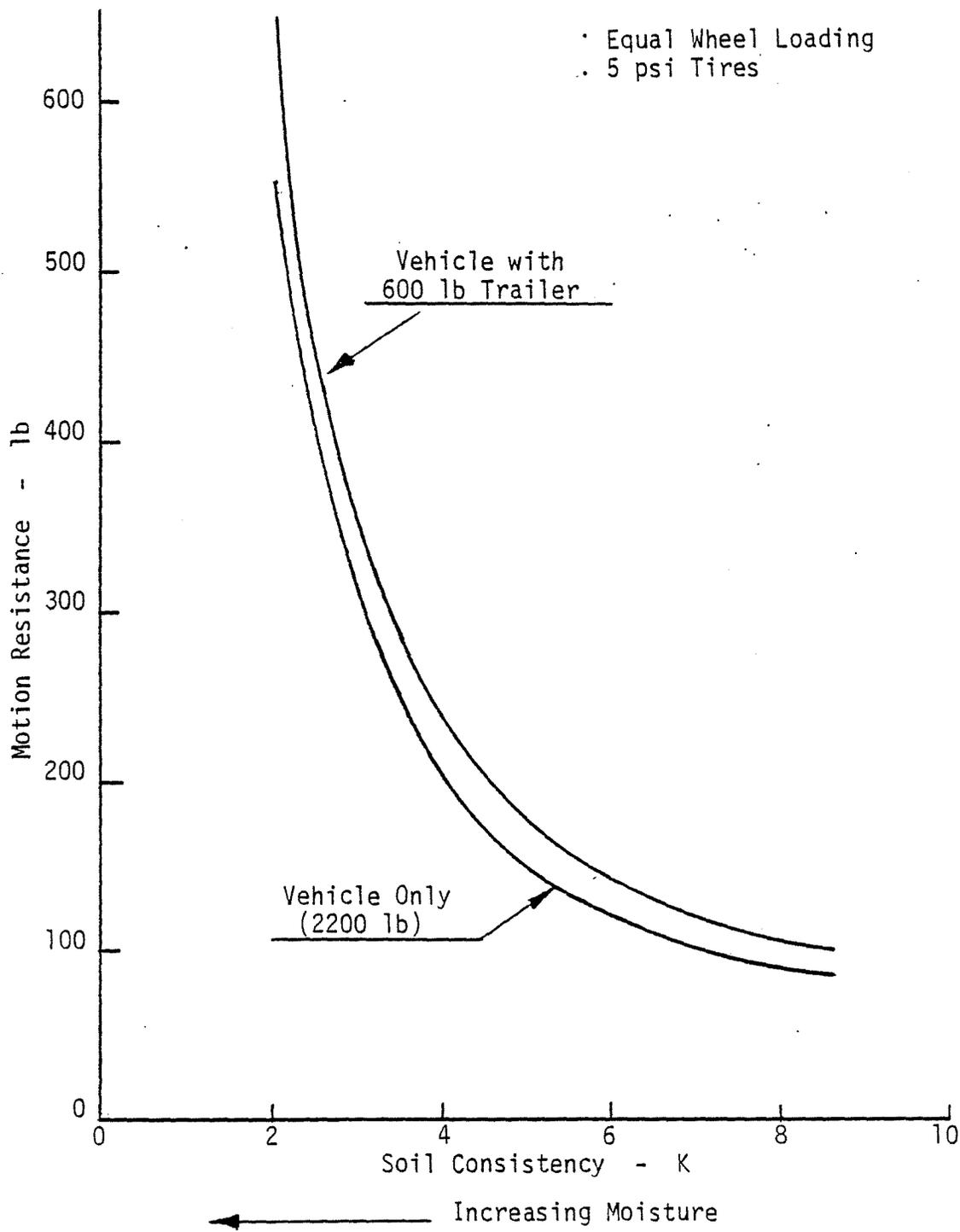


Figure 5 - MERV Motion Resistance as a Function of Soil Consistency

(Relatively Dry Sandy Soils)

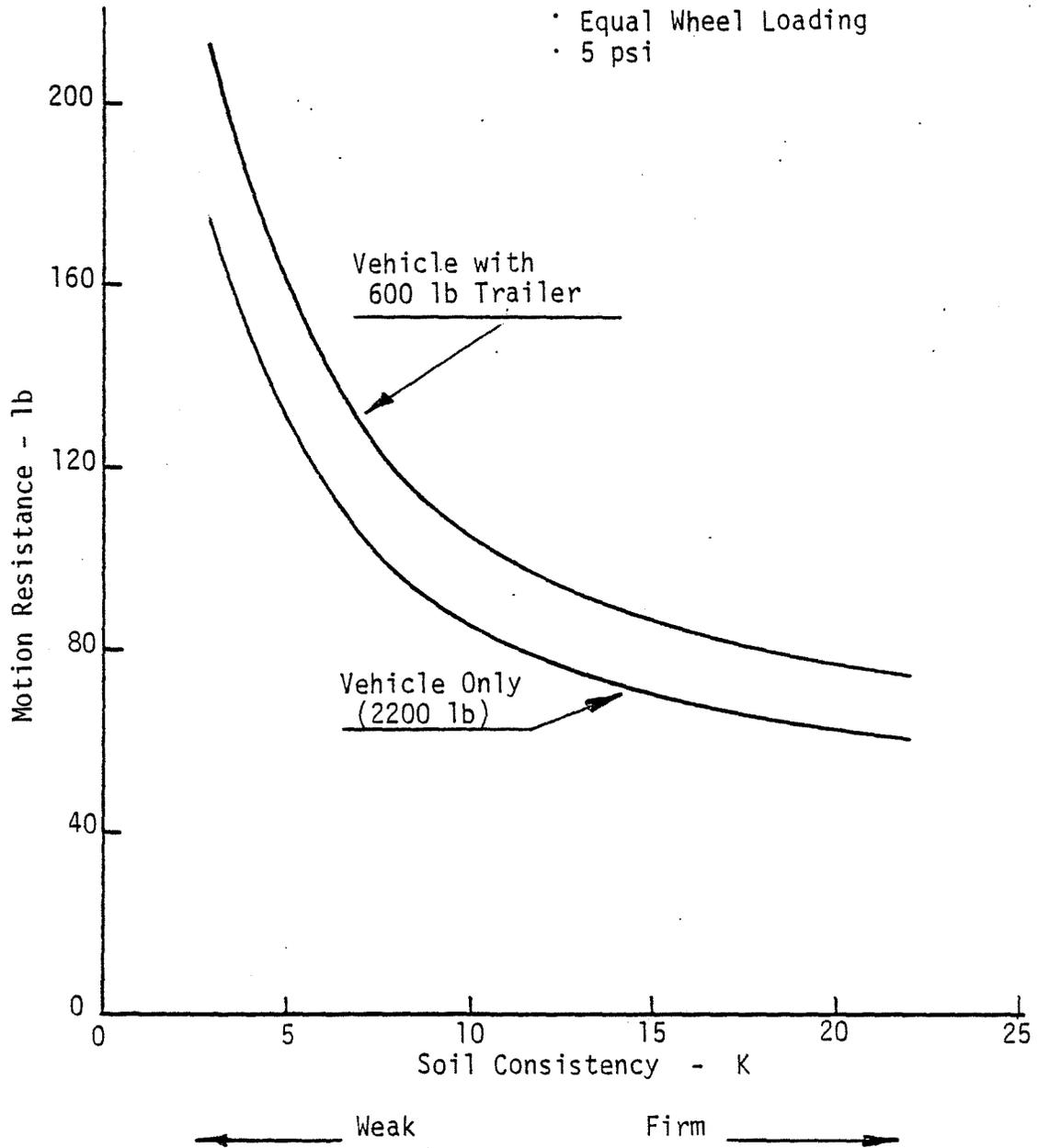


Figure 6 - MERV Motion Resistance as a Function of Soil Consistency

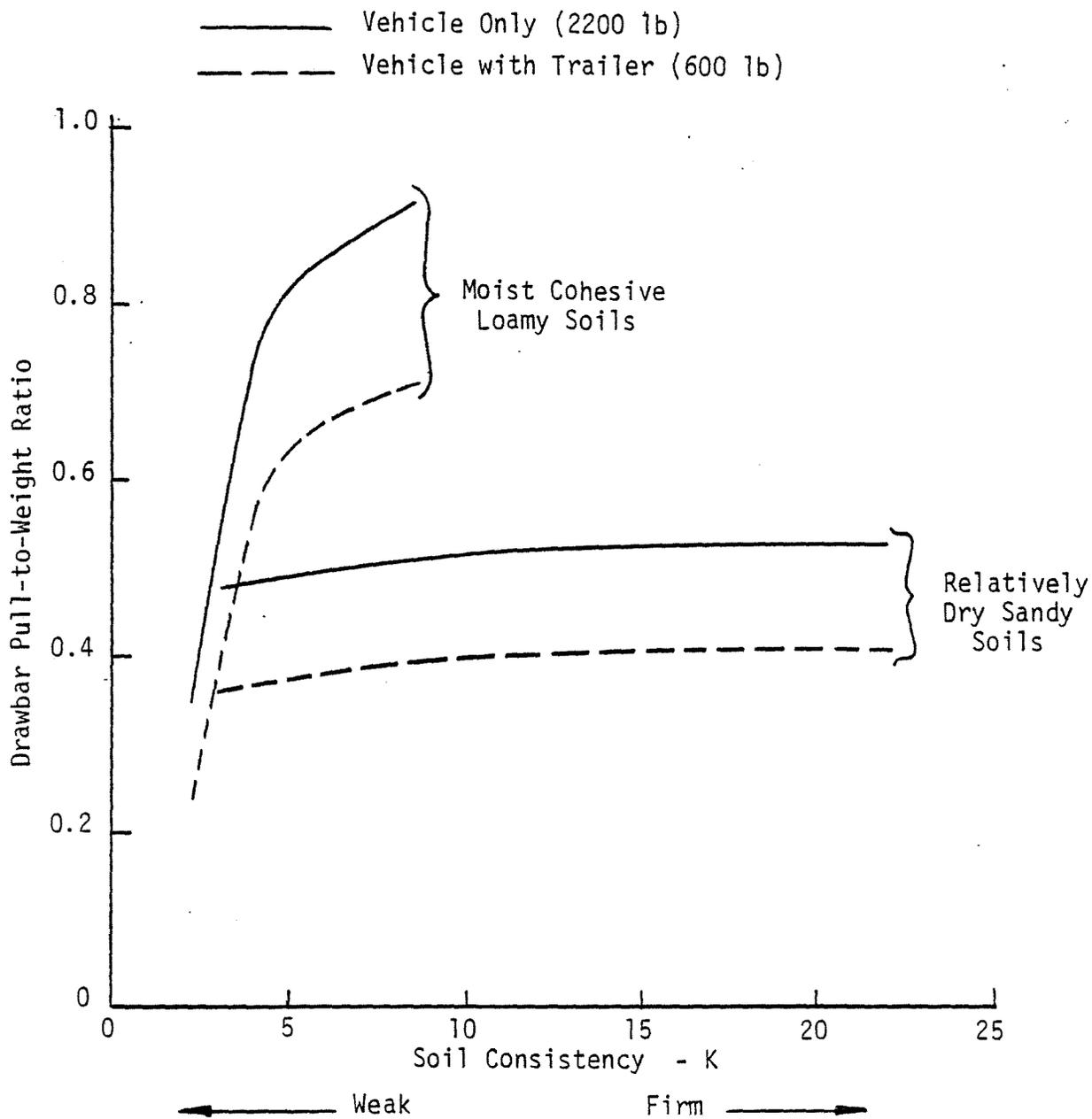


Figure 7 - MERV Drawbar Pull Capability as a Function of Soil Consistency

With respect to the mine demonstration tests, overall the MERV exhibited excellent mobility characteristics. This mine had several flooded and muddy areas which provided an opportunity to assess MERV soft soil performance. Although a person could sink to a depth of 3 or 4 inches in these areas, the high flotation tires enabled MERV to operate with relative ease. Obstacles such as rubble, rail tracks and ties, and timbers were also plentiful but, although the vehicle bottomed out several times, it was always able to proceed. The formal underground demonstration lasted about 4 1/2 hours, at all times with the trailer in tow. Furthermore, there were always at least two people in the vehicle and two on the trailer. Often, extra people rode on both the vehicle and trailer.

### CONCLUSIONS

Within the imposed dimensional, payload and mine permissible constraints, the MERV configuration is considered to be the optimum achievable from the point of view of mobility performance.

Transmission shifting is sometimes difficult. Driver training may improve the situation.

Emergency braking capacity appears to be inadequate.

The power train does not appear to be optimum, primarily with respect to efficiency. This conclusion is partly based on the motor-performance curves shown in Figure 4 which show relatively low motor efficiencies over most of the operating range. Also, efficiencies of the speed-reduction system have been estimated to be as low as 80%. If these assertions are correct, battery energy and power requirements are being unduly penalized.

The last three conclusions stated above are probably due to the desire to minimize first costs by adapting an existing vehicle and utilizing "off the shelf" components. This aim should be weighed against other factors such as reliability and operating range. A comprehensive test and evaluation program should provide the information required to formulate specifications for a "next generation" vehicle.

## APPENDIX

COMMENTS ON MERV BASED ON ABOVE-GROUND DEMONSTRATION TESTSIntroduction

Above-ground demonstrations for the Mine Safety Appliances Company (MSA) mine emergency rescue vehicle (MERV) were conducted for Bureau of Mines personnel at MSA near Evans City, Pennsylvania, on 14 June 1973. In addition to MSA and BuMines personnel, representatives of the ATV Manufacturing Company, designers and fabricators of the vehicle, and Delco Electronics-Santa Barbara Operations, mobility consultants, were also in attendance. (Messrs. William Probert and Joseph P. Finelli represented the latter organization as observers.) An informal demonstration of about one hour's duration was also given at a mine that afternoon, which the Delco representatives were unable to attend.

The purpose of the above-ground tests was to demonstrate conformance of the vehicle to various design and performance requirements, including:

- Deadweight - Maximum 1500 pounds including batteries, providing structural strength of vehicle meets safe design standards.
- Payload - Maximum 1000 pounds, including life support and instrumentation.
- Ground Clearance - Minimum of five inches with a target of six inches. Shall be able to traverse over a 12-inch diameter log.
- Grades - Operate on approximately 45 percent grades. Must be able to traverse from a horizontal surface to a surface which abruptly forms a 45 percent grade.
- Steering - Provisions for independent control of right or left side wheels so that either side can be powered or braked independently.
- Turning Radius - Can turn in its own length.
- Speed - 0 to 7 mph in both directions with SCR, or equivalent, speed control.

The above were all met with the exception of the deadweight and speed requirements. Empty weight during the tests was on the order of 1650 lbs and will probably increase further. Speed in the forward direction with trailer and two passengers was approximately 5.5 miles per hour. Speed in reverse was not measured. This deficiency in speed is considered relatively unimportant. Furthermore, the reason for the stated reverse-speed capability is not clear.

In addition to the above, it was necessary to demonstrate that the vehicle could be lowered safely into a mine below the cage of an elevator. This was accomplished by suspending the vehicle on end from its lifting lugs for a period of time and then operating the vehicle. Minor interference problems between various parts of the vehicle and the floor were noted while the vehicle was being lifted. These could be easily corrected in any future design.

Prior to the formal demonstrations of June 14, MSA, ATV and Delco personnel "dry ran" the scheduled above-ground vehicle tests on June 13.

Following are preliminary comments and suggestions by the Delco representatives as a result of their observations during those two days.

## DISCUSSION

Within the limitations imposed by factors such as dimensional and payload constraints, the requirements of Bureau of Mines Schedules, such as 2G, and the desire to minimize first cost by adapting an existing vehicle design, it is our opinion that, overall, the present MERV represents a good first attempt at creating a battery-powered, permissible vehicle for mine rescue operations.

It is felt that the use of low-pressure 26 x 12-2PR tires located on 30-inch centers has resulted in an optimum configuration from the point of view of overall mobility performance, although various compromises were necessary.

Soft soil mobility should be excellent due to the large, low-pressure tires, even though it is our understanding that the empty vehicle target weight has been exceeded by 10% or more. However, the increased battery energy consumption, due to this, may turn out to be a problem, depending on the mission profile over which the vehicle is intended to operate.

Angles of approach and departure are also excellent, with the possible exception of some local protuberances, such

as the running lights. This aids in the negotiation of obstacles and permits easy transition from a horizontal surface to steep grades. It was noted, however, that the rear of the trailer did contact the horizontal ground surface during the transition to the 45 percent grade.

Performance over obstacles such as logs, beams and rubble should be generally good, although situations are conceivable that could possibly cause the vehicle to hang-up. For example, in weak soils hang-up is possible if the vehicle bottoms out on an obstacle and the wheels in contact with the ground are unable to develop sufficient tractive effort to enable the vehicle to surmount the obstacle. Bottoming on an obstacle (and this is particularly noticeable when negotiating an obstacle such as a telephone pole) is due to the wheel spacing and limited ground clearance. However, little if anything can be done to alleviate this condition unless dimensional constraints, such as length and height, are alleviated. Problems could also occur during operation in low seams due to the nose-up attitude of the vehicle when negotiating obstacles, and the limited clearance between the top of the seam and the vehicle crew and victims.

Maneuverability is excellent. The skid-steer design permits steering to be accomplished either by braking one side of the vehicle and driving the other, or by driving the two sides in opposite directions, resulting in a pivot turn. It should be noted, however, that this type of steering requires large amounts of power; therefore, sharp turns should be made only when absolutely necessary.

Based on the implied ground-rule of utilizing an existing vehicle design and components to the greatest extent possible, the use of a single electric-drive motor instead of two or more is probably the simplest, cheapest and lightest approach. However, this is at the expense of redundancy, or emergency "get home" capability. The SCR chopper is an excellent means of accomplishing motor control, providing smooth, efficient performance.

It was noted during a series of runs that neither the service brakes or parking brakes were adequate (separately) to hold the vehicle on a 45% grade. Both had to be on simultaneously. Since this requires actuating three levers, it may prove a difficult task for an average driver. The present braking capacity is not known to the writers, nor the steepness and length of typical grades in mines. However, circumstances may exist where the driver would like to control easily the rate of descent down a long grade, to park on a grade without having to apply the transmission service brakes, or to park and leave the vehicle. The parking brake should, therefore, have

sufficient capacity to maintain the vehicle, with crew and loaded trailer, on the steepest slope on which the vehicle is expected to operate. The mechanical service brakes should be capable of preventing acceleration of the vehicle and/or stopping it on long, steep slopes. If the present brakes are not capable of accomplishing this under expected operating conditions, the following alternatives should be considered:

- Provide driver training to make best use of the existing system; for example, if the vehicle is accelerating down a slope even with the brakes applied, throw the transmission in reverse.
- Provide increased mechanical braking capacity.
- Add electrical braking capability to supplement the mechanical brakes, especially for operation on long slopes.

The permissibility requirements of Bureau of Mines Schedule 2G appears to impose severe weight and space penalties on the vehicle. It was our impression that MSA personnel feel that many of these may be outmoded or at least not necessarily applicable to an application such as the MERV. If this is correct, it is suggested that these requirements be carefully reviewed and specific recommendations made for amendments or waivers for future vehicles.

APPENDIX D

CELL EVALUATION TESTS FOR THE SILVER-ZINC CELLS

TEN (10) CYCLE - CHARGE/DISCHARGE  
EVALUATION TEST PROCEDURE  
Y.E.C. LR290-1 SILVER-ZINC CELLS  
FOR  
MINE SAFETY APPLIANCES CO.  
P.O. No. F-79737  
Y.E.C. REF. 20413

**Yardney**  
ELECTRIC CORPORATION

*Pioneers in Compact Power®*

**YARDNEY ELECTRIC DIVISION**

82 MECHANIC STREET, PAWCATUCK, CONN. 02891

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TABLE I - FORMATION RESULTS

<u>Cycle Number</u>	<u>Cell Number</u>	<u>Ic</u>	<u>VF</u>	<u>Input A.H.</u>	<u>Id</u>	<u>VF</u>	<u>V Plateau</u>	<u>Output A.H.</u>	<u>Appendix I Page Number</u>
1	1	8.0 A**	2.05	526**	40A	1.1V	1.51	477.2	1, 2
1	2	8.0 A	2.05	520	40A	1.1V	1.51	478.0	1, 2
2	1	10.0 A	2.05	465.8	60A	1.1V	1.50	469.8	3, 4
2	2	10.0 A	2.05	465.8	60A	1.1V	1.50	468.0	3, 4
1	3	8.0 A**	2.05	516.0**	40A	1.1V	1.50	500	5, 6
2	3	40 A	2.05	478.0	*	-	-	367.4	7, 8

Table I - Notes:

\* The Discharge Profile was as follows: Discharge for 8 hours

1. 1st hour - 73 amperes

2. 2nd - 7th hour - 36 minutes at 37 amps, 9 minutes at 73 amps, 15 minutes at 15 amps.

3. 8th hour - 73 amperes

\*\* Includes a 4-hour 8 ampere top charge after an eight (8) hour rest.

## 3. 8th hour - .73 amperes

This discharge constitutes a 367.4 A.H. output.

b. Charge:

1. 10 amperes to a cutoff of 2.05 V. After the fifth discharge cycles, all cells were drained at 37.0 amperes to a cutoff of 1.20 V to determine the capacity as compared to the original formation capacity. A tabulation of A.H. output versus cycle number is given in Table II, as follows:

TABLE II - DISCHARGE OUTPUT versus CYCLE NUMBER

<u>Cell No.</u>	<u>Cycle No.</u>	<u>A.H. Out</u>
1	Avg F1 & F2	473.5
1	5	455.46
1	10	367.4*
2	Avg F1 & F2	473.0
2	5	448.84
2	10	367.4*
3	F1	500
3	5	454.35
3	10	367.4*

## Table II Notes:

- \* Cell #1 - 367.4 A.H. to 1.388V
- Cell #2 - 367.4 A.H. to 1.009V
- Cell #3 - 367.4 A.H. to 1.335V

The three (3) cells met the requirement of 367.4 A.H. minimum output for ten (10) cycles as required by M.S.A. P.O. #F-79737. The cell case temperature was recorded during cycle nine (9) discharge and during cycle ten (10) charge (R.T. ambient). The cell case temperature during these cycles is tabulated in Table III as follows:

TABLE III

<u>Cycle Number</u>	<u>Maximum Case Temperature</u>
9 - discharge start	80°F
9 - discharge end	121°F
10 - charge start	80°F
10 - charge end	85°F

#### 1.4 CONCLUSIONS

The LR290-1 silver-zinc cell meets the requirements of 367.4 A.H. output for the ten (10) charge/discharge cycles as outlined in Paragraph 1.3.

The LR290-1 cell exceeds the design goal of 5 deep cycles of 367.4 A.H. or above as described in "Technical Proposal to Mine Safety Appliances for Rechargeable Silver-Zinc Battery for Emergency Mine Vehicle" of September 1972.

FORMATION DATA

APPENDIX I

# YARDNEY ELECTRIC CORP.

## DATA SHEET

R/T Lab  
Control #278

172

LR290-1

CHARGE; I c 8.0A - 2.05V

PROJ. NO C-20277

DISCHARGE; I c \_\_\_\_\_

DATE 10/16/72

CELL NO. 1, 2

TESTER W.P., LF, Jr., E.H.

WITNESSED AS

CYCLE NO. F-1

REMARKS:

I c 8.0A - 2.05V

Top Charge

CELL NO.	1	2				1	2		1	2
INPUT A.H.									8A-	4 hrs.
V <sub>F</sub>										
OCV										
START. TIME										
1400	2	1.635	1.638		2000	48	1938	1940	1.802	1.801
1600	4	1.642	1.642		2200	50	1937	1940	2.106	2.100
1800	6	1.645	1.645		2300	51	1938	1940	2.107	2.100
2000	8	1.647	1.647		2400	52	1940	1940	2.105	2.097
2200	10	1.649	1.652		0900	53	1.932	1.926	2.103	2.095
2400	12	1.679	1.688		1000	54	1.940	1.934		
1000	14	1.889	1.875		1100	55	1.947	1.947		
1200	16	1.917	1.926		1200	56	1.948	1.951		
1400	18	1.925	1.917		1300	57	1.957	1.952		
1600	20	1.933	1.920		1400	58	1.959	1.950		
1800	22	1.933	1.926		1500	59	1.993	1.988		
2000	24	1.923	1.935		1600	60	1.997	1.990		
2200	26	1.917	1.933		1700	61	2033	205		
2400	28	1.914	1.924		1800	62	205			
0200	30	1.922	1.925		1900	63				
0400	32				2000	64				
0600	34									
0800	36	1.918	1.920							
1000	38	1.920	1.923							
1200	40	1.924	1.927							
1400	42	1.932	1.934							
1600	44	1.930	1.930							
1800	46	1.938	1.939				1745	1700		
HRS./MIN							61.75	61.0		
OUTPUT A.H.							494.0	488.0		

REMARKS:

4 hr top charge 32.0 32.0  
TOTAL AH 526.0 520.0

# YARDNEY ELECTRIC CORP.

## DATA SHEET

R/T Lab  
Control #278

173

LR290-1

CHARGE; Icn \_\_\_\_\_

PROJ. NO. C-20277

DISCHARGE; Ia 40A - 1.10V

DATE 10/20/72

CELL NO. 1, 2

TESTER LF, Jr. W.P. E.H.

WITNESSED AB

CYCLE NO. F-1

REMARKS:

Id 40.0A - 1.10V

5      6

CELL NO.	1	2					1	2
INPUT A.H.								
Vf								
OCV	1.862	1.862						
START. TIME	1.769	1.779			0900	11 hrs	1.397	1.390
	15	1.727	1.744			30	1.381	1.375
	30	1.694	1.718		1000	12hrs	1.100	1.100
	45	1.669	1.669			30		
1500	1 hr	1.620	1.668					
	30	1.512	1.512					
1600	2 hrs	1.517	1.515					
	30	1.518	1.517					
1700	3 hrs	1519	1519					
	30	1521	1521					
1800	4 hrs	1520	1521					
	30	1519	1523					
1900	5 hrs	1519	1521					
	30	1520	1522					
2000	6 hrs	1516	1518					
	30	1513	1514					
2100	7 hrs	1503	1516					
	30	1506	1510					
2200	8 hrs	1499	1504					
	30	1492	1497					
2300	9 hrs	1485	1487					
	30	1476	1476					
2400	10 hrs	1460	1458					
	30	1400	1.390				0956	0957
HRS./MIN							11.93	11.95
OUTPUT A.H.							477.2	478.0

REMARKS:

# YARDNEY ELECTRIC CORP. DATA SHEET

174

LR 290-1

CHARGE; I<sub>ch</sub> 10A - 2.05V

PROJ. NO. C-20277

R/T Lab  
Control #278

DISCHARGE; I<sub>d</sub> \_\_\_\_\_

DATE 10/23/72

CELL NO. 1, 2

TESTER W.P., LF Jr., E.H.

WITNESSED YJB

CYCLE NO. F-2

REMARKS:

I c 10.0A - 2.05V

1400

/CELL NO.		1	2				1	2		
INPUT A.H.										
V <sub>F</sub>										
OCV		1.582	1.582							
START. TIME		1.636	1.637		1000	44	1.952	1.951		
1600	2	1.628	1.628		1100	45	1.964	1.960		
1800	4	1.634	1.634		1200	46	1.988	1.980		
2000	6	1.639	1.638		1300	47	2.061	2.050		
2200	8	1.639	1.639		1400	48				
2400	10	1.642	1.644		1500	49				
0200	12				1600	50				
0400	14									
0600	16									
0800	18	1.900	1.899							
1000	20	1.902	1.902							
1200	22	1.904	1.905							
1400	24	1.910	1.910							
1600	26	1.918	1.917							
1800	28	1.931	1.929							
2000	30	1.936	1.930							
2200	32	1.941	1.940							
2400	34	1.938	1.936							
0200	36									
0400	38									
0600	40									
0700	41	1.945	1.944				1235	1235		
0800	42	1.947	1.946							
0900	43	1.948	1.947							
HRS./MIN							46.58	46.58		
OUTPUT A.H.							465.8	465.8		

REMARKS:

# YARDNEY ELECTRIC CORP.

R/T Lab  
Control #278

175

LR 290-1

## DATA SHEET

CHARGE; Icn \_\_\_\_\_ PROJ. NO. C-20277

DISCHARGE; I<sub>o</sub> 60A - 1.10V DATE: 10/25/72

CELL NO. 1, 2

TESTER LF, Jr, W.P., E.H. WITNESSED J.A.B

CYCLE NO. F-2

REMARKS: I d: 60.0A - 1.10V

/CELL NO.		1	2						
INPUT A.H.									
V <sub>F</sub>									
OCV		1.859	1.859						
START. TIME		1.709	1.708						
	15	1.554	1.581						
	30	1.487	1.486						
	45	1.490	1.488						
1700	1 hr	1.491	1.489						
	30	1.505	1.503						
1800	2 hrs	1.508	1.506						
	30	1.509	1.507						
1900	3 hrs	1.508	1.506						
	30	1.507	1.505						
2000	4 hrs	1.507	1.504						
	30	1.502	1.498						
2100	5 hrs	1.493	1.489						
	30	1.482	1.477						
2200	6 hrs	1.467	1.462						
	30	1.450	1.446						
2300	7 hrs	1.438	1.432						
	30	1.416	1.412						
2400	8 hrs	1.000	1.100						
	30								
	9 hrs								
		2.350	2.348						
NRS./MIN	→	7.85	7.8						
OUTPUT A.H.	→	469.8	465.0						

REMARKS:

# YARDNEY ELECTRIC CORP.

## DATA SHEET

R/T Lab  
Control #278

176

LR290-1

CHARGE; I<sub>c</sub> 8.0A - 2.05V

PROJ. NO. C-20277

DISCHARGE; I<sub>c</sub> \_\_\_\_\_

DATE 10/27/72

CELL NO. 3

TESTER E.H., LF, Jr., W.P.

WITNESSED V.O.B.

CYCLE NO. F-1

**REMARKS:**

I<sub>c</sub> 8.0A - 2.05V Plus 4 Hours Overcharge

/CELL NO.										
	3									
INPUT A.H.										
VF										
OCV										
START. TIME		1123		48	0	1030	2.050			
2400	2	1635		50	1	1130	2.110			
		4		52	2	1230	2.113			
		6		54	3	1330	2.115			
		8		56	4	1430	2.115			
		10		58			1.955			
		12		60			1.963			
		14		61			2.050			
11-28	16	1.907		62						
		18		63						
		20		64						
		22								
		24								
		26								
		28								
		30								
		32								
		34								
11-29	36	1.936								
		38								
		40								
		42								
		44								
		46				1030				
HRS./MIN	→						64.5			
OUTPUT A.H.	→						516.0			

REMARKS:

# YARDNEY ELECTRIC CORP.

177

LR 290-1

## DATA SHEET

R/T Lab.  
Control #278

CHARGE; Icm \_\_\_\_\_ PROJ. NO. C-20277

DISCHARGE; Ia 40A - 1.10V DATE 10/30/72

CELL NO. 3

TESTER LF, Jr., W.P., E.H. WITNESSED S.J.B.

CYCLE NO. F-1

REMARKS:

I d 40.0A - 1.10V

10

/CELL NO.									
		3						3	
INPUT A.M.									
V <sub>F</sub>									
OCV		1.864							
START. TIME									
	0	1.755		1000	11 hrs	1.429			
	15	1.677			30	1.417			
	30	1.631		1100	12 hrs	1.389			
	45	1.572			30	1.100			
1600	1 hr	1.517		1200	13 hrs				
	30	1.493			30				
1700	2 hrs	1.498		1300	14 hrs				
	30	1.504			30				
1800	3 hrs	1.506		1400	15 hrs				
	30	1.510							
1900	4 hrs	1511							
	30	1510							
2000	5 hrs	1511							
	30	1512							
2100	6 hrs	1511							
	30	1.508							
2200	7 hrs	1.507							
	30	1504							
2300	8 hrs	1500							
	30	1494							
2400	9 hrs	1490							
	30	1.443							
0900	10hrs	1.440							
	30	1.437				1130			
HRS./MIN					→	12.50			
OUTPUT A.M.					→	500.			

REMARKS:

DATA SHEET

CHARGE; Icn 40A-2.05V PROJ. NO. C-20277

DISCHARGE; Ia \_\_\_\_\_ DATE 10/31/72

CELL NO. 3

TESTER W.D., I.E., Jr. E.H. WITNESSED J.F.D.

CYCLE NO. F-2

REMARKS:

CELL NO.	3		3			
		Temp.				
INPUT A.H.						
V <sub>F</sub>						
OCV	1.589	84.0				
START. TIME	1.656	84.0	0900	12 hrs.	2.050	
	30 1.653	84.0		30		
1400	1 hr 1.615	82.0				
	30 1.615	80.0				
1500	2 hrs 1.615	80.0				
	30 1.916	80.0				
1600	3 hrs 1.917	80.0				
	30 1.925	82.0				
1700	4 hrs 1.93	85.0				
	30 1.92	86.0				
1800	4 hrs 1.92	88.0				
	30 1.93	90.0				
1900	6 hrs 1.93	92.0				
	30 1.93	94.0				
2000	7 hrs 1.94	95.0				
	30 1.95	96.0				
2100	8 hrs 1.95	96.0				
	30 1.95	96.0				
2200	9 hrs 1.95	97.0				
	30 1.96	98.0				
2300	10 hr 1.96	98.0				
	30 1.97	100°				
2400	11 hr 1.97	100				
	30 2.00	80.0		0857		
HRS./MIN				11.95		
OUTPUT A.H.				478.0		

REMARKS:

# YARDNEY ELECTRIC CORP.

179

LR290-1

## DATA SHEET

CHARGE; Icn \_\_\_\_\_

PROJ. NO. C-20277

DISCHARGE; Ia See Below

DATE 11/1/72

CELL NO. 3

TESTER LE, Jr., W.P. E.H.

WITNESSED J.G.B.

CYCLE NO. F-2

REMARKS:

1200

CELL NO.	Time	I	3		Time	I	3		Time	I	3	
INPUT A.H.												
Vf												
OCV			1.859									
START. TIME		73A	1.709	10	10	37A	1.520		10	10	37A	1.511
	15		1.603	20	20		1.518		20	20		1.507
	30		1.525	36	36		1.517		36	36		1.505
	45		1.471	41	5	73A	1.472		41	5	73A	1.454
1300	1 hr		1.456	45	9		1.471		45	9		1.450
	10	37A	1.514	50	5	15A	1.553		50	5	15A	1.543
	20		1.512	55	10		1.553		55	10		1.544
	30		1.513	1600	15		1.553		1900	15		1.544
	36		1.514	10	10	37A	1.519		15	15	73A	1.445
	41	5	73A	1.467	20	20		1.517	30	30		1.436
	45	9		1.466	36	36		1.515	45	45		1.436
	50	5	15A	1.566	41	5	73A	1.469	2000	1 hr		1.435
	55	10		1.562	45	9		1.467				
1400	15		1.560	50	5	15A	1.547					
	10	37A	1.519	55	10		1.546					
	20		1.518	1700	15		1.545					
	30		1.517	10	10	37A	1.516					
	36		1.517	20	20		1.516					
	41	5	73A	1.471	36	36		1.513				
	45	9		1.470	41	5	73A	1.467				
	50	5	15A	1.555	45	9		1.466				
	55	10		1.555	50	5	15A	1.550				
1500	15		1.554	55	10		1.549					
				1800	15		1.547					
HRS./MIN												
OUTPUT A.H.												367.4

REMARKS:

TEN CYCLE DATA

APPENDIX II

# YARDNEY ELECTRIC CORP. DATA SHEET

LR 290-1

R/T Lab 181  
Control #278

CHARGE; I<sub>c</sub> 10A-2.05V

PROJ. NO. 20413

DISCHARGE; I<sub>c</sub> \_\_\_\_\_

DATE 10/26/72

CELL NO. 1, 2,

TESTER E.H., LF, Jr. W.P.

WITNESSED *[Signature]*

CYCLE NO. 1

**REMARKS:**

I<sub>c</sub> 10.0A-2.05V

CELL NO.	1	2				1	2		
INPUT A.H.									
V <sub>F</sub>									
O.C.V.	1.583	1.594							
START. TIME	0	1.640	1.640	47	1700	1956	1954		
1200	2	1.630	1.630	48	1800	1962	1962		
1400	4	1.637	1.636	49	1900	205	205		
1600	6	1.640	1.639	50	2000				
1800	8	1.641	1.640	51	2100				
2000	10	1.646	1.643	52	2200				
2200	12	1.615	1.621	53	2300				
2400	14	1.605	1.607	54	2400				
0200	16								
0400	18								
0600	20								
0800	22	1.904	1.903						
1000	24	1.909	1.908						
1200	26	1.916	1.915						
1400	28	1.926	1.923						
1600	30	1.934	1.931						
1800	32	1.937	1.938						
2000	34	1.937	1.937						
2200	36	1.945	1.940						
2400	38	1.942	1.940						
1000	40	1.946	1.956						
1200	42	1.952	1.950						
1400	44	1.946	1.950						
1600	46	1.954	1.954			1855	1900		
HRS./MIN						48.92	49.0		
OUTPUT A.H.						489.2	490.0		

REMARKS:

# YARDNEY ELECTRIC CORP.

## DATA SHEET

LR 290-1

R/T Lab 182  
Control #278

CHARGE; I<sub>c</sub> 10A-2.05V PROJ. NO. 20413

DISCHARGE; I<sub>c</sub> \_\_\_\_\_ DATE \_\_\_\_\_

CELL NO. 3

TESTER W.P., LF Jr. E.H. WITNESSED A.B.

CYCLE NO. 1

REMARKS:

I<sub>c</sub> 10.0A - 2.05V

/CELL NO.									
			3						
INPUT A.H.									
V <sub>F</sub>									
OCV			1.604						
START. TIME			1.634		1400	44			
1100	2		1.633		1500	45			
1300	4		1.640		1600	46			
1500	6		1.648		1700	47			
1700	8		1.912		1800	48			
1900	10		1.903						
2100	12		1.901						
2300	14		1.904						
0100	16								
0300	18								
0500	20								
0700	22		1.944						
0900	24		1.943						
1100	26		1.943						
1300	28		1.946						
1500	30		1.948						
1700	32		1.947						
1900	34		1.952						
2100	36		1.956						
2300	38		1.990						
1000	40		2.050						
1100	41								
1200	42								
1300	43		0830						
HRS./MIN		→	38.50						
OUTPUT A.H.		→	385.0						

REMARKS:

FORM #YEC-20

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 183

Control #278

CHARGE; Icc \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; Ia See Remarks DATE 11/10/72

CELL NO. 1, 2, 3

TESTER: L.F. Jr. W.P., E.H. WITNESSED P.A.B.

CYCLE NO. 1

REMARKS: The Discharge Profile is as follows:

Discharge for 8 hr;

1) 1st hour - 73 amperes

2) 2nd-7th hour - 36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.

3) 8th hour - 73 amperes

367.40 AH out  
each cell.

000

CELL NO.		I	1	2	3			I	1	2	3
INPUT A.M.											
VP											
OCV			1.860	1.860	1.860						
START. TIME		73A	1.575	1.523	1.540		50	15A	1.556	1.556	1.551
	15		1.459	1.444	1.426	1400	4 hrs.		1.555	1.556	1.551
	30		1.460	1.455	1.428		10	37A	1.521	1.522	1.514
	45		1.469	1.467	1.447		20		1.519	1.521	1.511
1100	1 Hr.		1.475	1.474	1.458		36		1.517	1.519	1.509
	10	37A	1.521	1.521	1.512		41	73A	1.473	1.475	1.461
	20		1.523	1.523	1.514		45		1.470	1.474	1.460
	36		1.523	1.523	1.515		50	15A	1.554	1.554	1.549
	41	73A	1.484	1.484	1.472	1500	5 Hrs.		1.553	1.554	1.549
	45		1.483	1.484	1.470		10	37A	1.516	1.518	1.507
	50	15A	1.564	1.563	1.554		20		1.515	1.517	1.505
1200	2 Hrs		1.562	1.561	1.554		36		1.510	1.513	1.501
	10	37A	1.524	1.524	1.517		41	73A	1.461	1.464	1.450
	20		1.524	1.523	1.515		45		1.459	1.462	1.448
	36		1.522	1.523	1.515		50	15A	1.549	1.550	1.544
	41	73A	1.483	1.484	1.472	1600	6 Hrs.		1.548	1.550	1.544
	45		1.481	1.483	1.470		10	37A	1.507	1.510	1.498
	50	15A	1.559	1.559	1.553		20		1.504	1.507	1.495
1300	3 Hrs		1.557	1.557	1.552		36		1.500	1.504	1.492
	10	37A	1.523	1.524	1.517		41	73A	1.449	1.452	1.440
	20		1.522	1.523	1.515		45		1.446	1.449	1.438
	36		1.521	1.522	1.514		50	15A	1.542	1.544	1.538
	41	73A	1.479	1.481	1.468	1700	7 Hrs.		1.541	1.543	1.573
	45		1.478	1.480	1.467		15	73A	1.442	1.446	1.436
HRS./MIN							30		1.443	1.446	1.438
OUTPUT A.M.							45		1.441	1.444	1.438

REMARKS:

1800 8 Hrs.

1440 1443 FORM 1438 REC-21

# YARDNEY ELECTRIC CORP.

LR 290-1

## DATA SHEET

R/T Lab 184  
Control #278

CHARGE; I c 10A-2.05V PROJ. NO. 20413

DISCHARGE; I c \_\_\_\_\_ DATE 11/13/72

CELL NO. 1, 2, 3

TESTER W.P., LF, Jr., E.H. WITNESSED A.J.B.

CYCLE NO. 2

REMARKS:

I c 10.0A-2.05V

900

CELL NO.		1	2	3				
INPUT A.H.								
V <sub>F</sub>								
OCV		1.604	1.604	1.604				
START. TIME		1.654	1.654	1.639				
1100	2	1.633	1.634	1.631				
1300	4	1.643	1.644	1.641				
1500	6	1.923	1.925	1.650				
1700	8	1900	1901	1903				
1900	10	1900	1900	1900				
2100	12	1900	1900	1898				
2300	14	1903	1903	1899				
0100	16							
0300	18							
0500	20	1.939	1.940	1.929				
0700	22	1.939	1.939	1.940				
0900	24	1.940	1.940	1.942				
1100	26	1.941	1.941	1.944				
1300	28	1.941	1.942	1.942				
1500	30	1.945	1.944	1.945				
1700	32	1943	1942	1944				
1900	34	1949	1949	1949				
2100	36	1976	1970	1954				
2300	38	205	205	2012				
	40			205				
	42							
	44							
	46	2245	2250	2310				
HRS./MIN	→	37.75	37.83	38.16				
OUTPUT A.H.	→	377.5	378.3	381.6				

REMARKS:

# YARDNEY ELECTRIC CORP.

LR 290-1

## DATA SHEET

R/T Lab 186  
Control #278

CHARGE; I<sub>c</sub> 10A-2.05V

PROJ. NO. 20413

DISCHARGE; I<sub>d</sub> \_\_\_\_\_

DATE 11/15/72

CELL NO. 1, 2, 3

TESTER E.H. W.P.

WITNESSED S.J.B.

CYCLE NO. 3

REMARKS:

I<sub>c</sub> 10.0A - 2.05V

/CELL NO.		1	2	3						
INPUT A.H.										
V <sub>F</sub>										
OCV										
START. TIME		1618	1617	1615						
2000	2	1627	1628	1625						
2200	4	1639	1640	1637						
2400	6	1674	1644	1654						
0900	8	1.905	1.905	1.905						
1100	10	1.900	1.901	1.899						
1300	12	1.900	1.902	1.898						
1500	14	1.904	1.907	1.900						
1700	16	1912	1915	1903						
1900	18	1917	1921	1906						
2100	20	1943	1939	1925						
2300	22	1940	1940	1939						
1000	24	1.933	1.936	1.926						
1200	26	1.948	1.939	1.949						
1400	28	1.939	1.948	1.947						
1600	30	1.950	1.943	1.944						
1800	32	1946	1945	1947						
2000	34	1965	1962	1956						
2200	36	205	205	205						
	38									
	40									
	42									
	44									
	46	2115	2118	2200						
HRS./MIN	→	35.25	35.30	36.0						
OUTPUT A.H.	→	352.5	353.0	360.0						

REMARKS:

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 189  
Control #278

CHARGE; Ica \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; I<sub>a</sub> See Remarks DATE 11/27/72

CELL NO. 1, 2, 3

TESTER WP., W.F. Jr. WITNESSED S.J.B.

CYCLE NO. 4

REMARKS: The Discharge Profile is as follows:

Discharge for 8 hr;

1) 1st hour - 73 amperes

2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.

3) 8th hour-73 amperes

67.40 AH out  
each cell.

CELL NO.		I	1	2	3			I	1	2	3
INPUT A.H.											
V <sub>F</sub>											
OCV			1.850	1.850	1.850						
START. TIME		73A	1.723	1.721	1.714		50	15A	1.549	1.550	1.548
	15		1.671	1.672	1.649	1300	4 hrs		1.550	1.551	1.548
	30		1.636	1.643	1.611		10	37A	1.511	1.513	1.506
	45		1.599	1.612	1.584		20		1.508	1.510	1.503
1000	1 Hr		1.516	1.537	1.503		36		1.504	1.507	1.498
	10	37A	1.601	1.622	1.585		41	73A	1.447	1.450	1.438
	20		1.549	1.578	1.534		45		1.445	1.448	1.436
	36		1.519	1.520	1.515		50	15A	1.543	1.544	1.541
	41	73A	1.479	1.477	1.470	1400	5 Hrs.		1.543	1.545	1.541
	45		1.478	1.476	1.469		10	37A	1.495	1.498	1.490
	50	15A	1.570	1.572	1.568		20		1.490	1.494	1.486
1100	2 Hrs		1.555	1.557	1.553		36		1.484	1.488	1.481
	10	37A	1.523	1.523	1.519		41	73A	1.429	1.432	1.425
	20		1.521	1.521	1.517		45		1.429	1.432	1.426
	36		1.520	1.520	1.516		50	15A	1.531	1.534	1.533
	41	73A	1.476	1.476	1.469	1500	6 Hrs.		1.529	1.532	1.530
	45		1.474	1.474	1.467		10	37A	1.476	1.479	1.475
	50	15A	1.553	1.554	1.552		20		1.473	1.476	1.472
1200	3 Hrs		1.553	1.553	1.552		36		1.468	1.471	1.469
	10	37A	1.518	1.519	1.514		41	73A	1.420	1.422	1.416
	20		1.517	1.517	1.513		45		1.421	1.423	1.417
	36		1.515	1.516	1.511		50	15A	1.521	1.522	1.523
	41	73A	1.465	1.467	1.458	1600	7 Hrs		1.519	1.521	1.521
	45		1.463	1.465	1.456		15	73A	1.421	1.423	1.416
HRS./MIN							30		1.423	1.425	1.419
OUTPUT A.H.							45		1.424	1.426	1.420

REMARKS:

1700 8 Hrs.

1.423 1.425 1.421

FORM #YEC-20

# YARDNEY ELECTRIC CORP. DATA SHEET

LR 290-1

R/T Lab 190  
Control #278

CHARGE; I<sub>ch</sub> 10A-2.05V PROJ. NO. 20413

DISCHARGE; I<sub>d</sub> \_\_\_\_\_ DATE 11/27/72

CELL NO. 1, 2, 3

TESTER LF, Jr. W.P. WITNESSED S.J.B.

CYCLE NO. 5

REMARKS: I c 10.0A - 2.05V

CELL NO.		1	2	3						
INPUT A.H.										
V <sub>F</sub>										
OCV										
START. TIME		1.620	1.618	1.616						
2000	2									
2200	4									
2400	6									
0200	8									
0400	10									
0600	12	1.905	1.906	1.904						
0800	14	1.905	1.907	1.906						
1000	16	1.914	1.916	1.914						
1200	18	1.923	1.926	1.923						
1400	20	1.937	1.940	1.937						
1600	22									
1800	24									
2000	26									
0200	28									
0400	30									
0600	32									
0800	34	1.948	1.949	1.953						
1000	36	1.953	1.985	2.012						
1200	38	2.050	2.050	2.050						
	40									
	42									
	44									
	46	1098	1010	1006						
HRS./MIN	→	36.80	36.16	36.10						
OUTPUT A.H.	→	368.0	361.6	361.0						

REMARKS:

FORM #YEC-2

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 191  
Control #278

CHARGE; Ica \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; Ia See Remarks DATE 11/29/72

CELL NO. 1, 2, 3

TESTER LF, Jr., W.P.E.H. WITNESSED J.J.B.

CYCLE NO. 5

REMARKS: The Discharge Profile is as follows:

Discharge for 8 hr;

1) 1st hour - 73 amperes

2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.

3) 8th hour-73 amperes

67.40 AH out  
each cell.

CELL NO.		I	1	2	3			I	1	2	3
INPUT A.H.											
VF											
OCV			1.864	1.860	1.863						
START. TIME		73A	1.768	1.767	1.765		50	15A			
	15		1.730	1.727	1.714	1500	4 hrs		1.550	1.550	1.548
	30		1.709	1.708	1.684		10	37A	1.515	1.515	1.510
	45		1.687	1.690	1.668		20		1.514	1.513	1.508
1200	1 Hr.		1.628	1.645	1.618		36		1.510	1.509	1.504
	10	37A	1.694	1.711	1.691		41	73A	1.456	1.454	1.446
	20		1.642	1.667	1.640		45		1.452	1.451	1.442
	36		1.564	1.592	1.556		50	15A	1.544	1.544	1.541
	41	73A	1.481	1.480	1.472	1600	5 Hrs.		1.544	1.544	1.541
	45		1.479	1.477	1.469		10	37A	1.502	1.502	1.494
	50	15A	1.582	1.586	1.577		20		1.497	1.496	1.488
1300	2 Hrs		1.570	1.574	1.566		36		1.489	1.488	1.481
	10	37A	1.523	1.523	1.518		41	73A	1.430	1.430	1.420
	20		1.523	1.522	1.517		45		1.429	1.430	1.421
	36		1.522	1.522	1.517		50	15A	1.530	1.530	1.529
	41	73A	1.481	1.481	1.472	1700	6 Hrs.		1.532	1.532	1.531
	45		1.480	1.479	1.471		10	37A	1.482	1.483	1.479
	50	15A	1.554	1.554	1.551		20		1.476	1.476	1.473
1400	3 Hrs		1.552	1.553	1.550		36		1.468	1.469	1.467
	10	37A	1.523	1.523	1.518		41	73A	1.407	1.412	1.409
	20		1.521	1.521	1.516		45		1.414	1.415	1.409
	36		1.519	1.519	1.514		50	15A	1.524	1.524	1.524
	41	73A	1.473	1.472	1.465	1800	7 Hrs		1.517	1.516	1.518
	45		1.472	1.471	1.464		15	73A	1.408	1.410	1.408
HRS./MIN							30		1.432	1.433	1.427
OUTPUT A.H.							45		1.427	1.428	1.422

REMARKS:

1900 8 Hrs.

1426 1427 1420

FORM #YEC-20



# YARDNEY ELECTRIC CORP.

LR 290-1

## DATA SHEET

R/T Lab 193  
Control #278

CHARGE: I<sub>c</sub> 10A-2.05V PROJ. NO. 20413

DISCHARGE: I<sub>d</sub> \_\_\_\_\_ DATE 11/30/73

CELL NO. 1, 2, 3

TESTER L.F. Jr., W.P., E.H. WITNESSED A.J.B.

CYCLE NO. 6

REMARKS: I c 10.0A - 2.05V

/CELL NO.	1	2	3							
INPUT A.H.										
V <sub>F</sub>										
OCV										
START. TIME		1.655	1.654	1.690						
1000	2	1.634	1.635	1.630						
1200	4	1.640	1.641	1.637						
1400	6	1.642	1.643	1.639						
1600	8	1.664	1.664	1.655						
1800	10	1899	1900	1899						
2000	12	1897	1898	1896						
2200	14	1897	1898	1896						
2400	16	1900	1900	1897						
0200	18									
0400	20									
0600	22									
0800	24	1.928	1.921	1.919						
1000	26	1.940	1.934	1.934						
1200	28	1.933	1.939	1.937						
1400	30	1.933	1.938	1.940						
1600	32	1.939	1.940	1.941						
1800	34	1942	1942	1942						
2000	36	1942	1942	1942						
2200	38	1944	1943	1944						
2400	40	1946	1947	1947						
1000	42	1970	2006	1961						
1200	44	205	705	2.06						
	46	1100	1040	1145						
HRS./MIN	→	43.0	42.66	43.75						
OUTPUT A.H.	→	430.0	426.6	437.5						

300

12-1

REMARKS:

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 194  
Control #278

CHARGE; Icc \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; Ia See Remarks DATE 12/5/72

CELL NO. 1, 2, 3

TESTER L.F. Jr., E.H. WITNESSED S.J.B.

CYCLE NO. 6

REMARKS: The Discharge Profile is as follows:  
Discharge for 8 hr;

67.40 AH out  
each cell.

- 1) 1st hour - 73 amperes
- 2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.
- 3) 8th hour-73 amperes

CELL NO.		I	1	2	3				I	1	2	3
INPUT A.H.												
Vf												
OCV			1.862	1.862	1.862							
START. TIME		73A	1.748	1.746	1.744		50	15A	1.547	1.546	1.546	
	15		1700	1700	1683		1200	4 hrs	1.548	1.547	1.548	
	30		1.683	1.685	1.663			10	37A	1504	1501	1503
	45		1.661	1.669	1.650			20		1499	1497	1499
0900	1 Hr		1.626	1.643	1.619			36		1496	1494	1497
	10	37A	1692	1711	1691			41	73A	1437	1435	1436
	20		1659	1689	1665			45		1.436	1.434	1.435
	36		1.534	1.571	1.549			50	15A	1540	1539	1541
	41	73A	1.464	1.456	1.454		1300	5 Hrs.	1.541	1.540	1.592	
	45		1.463	1.455	1.454			10	37A	1.492	1.490	1.493
	50	15A	1.518	1.576	1.578			20		1.487	1.486	1.489
1000	2 Hrs		1.562	1.555	1.563			36		1.483	1.482	1.486
	10	37A	1516	1512	1511			41	73A	1.426	1.425	1.427
	20		1514	1510	1509			45		1426	1426	1428
	36		1513	1509	1508			50	15A	1530	1530	1534
	41	73A	1465	1458	1459		1400	6 Hrs.	1.530	1.530	1.534	
	45		1460	1453	1459			10	37A	1475	1475	1480
	50	15A	1556	1553	1554			20		1473	1473	1478
1100	3 Hrs		1550	1549	1549			36		1460	1469	1475
	10	37A	1513	1510	1511			41	73A	1418	1417	1421
	20		1511	1508	1509			45		1418	1416	1421
	36		1509	1505	1507			50	15A	1520	1520	1527
	41	73A	1453	1448	1450		1500	7 Hrs	1.516	1.515	1.523	
	45		1.452	1.447	1.449			15	73A	1.419	1.417	1.421
HRS./MIN								30		1.422	1.419	1.425
OUTPUT A.H.								45		1421	1417	1424

REMARKS: 1600 8 Hrs. 1.419 1.413 1.420 FORM #YEC-20

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 196  
Control #278

CHARGE; Icc \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; Icc See Remarks DATE 12/8/72

CELL NO. 1, 2, 3

TESTER LF, Jr., E.H. W.P. WITNESSED S.J.B.

CYCLE NO. 7

REMARKS: The Discharge Profile is as follows:

Discharge for 8 hr;

1) 1st hour - 73 amperes

2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.

3) 8th hour-73 amperes

367.40 AH out  
each cell.

CELL NO.		I	1	2	3			I	1	2	3
INPUT A.H.											
VP											
OCV			1.860	1.859	1.860						
START. TIME		73A	1753	1742	1746		50	15A	1.549	1.549	1.549
	15		1710	1702	1700	1800	4 hrs		1.548	1.547	1.548
	30		1.701	1.691	1.680		10	37A	1.505	1.504	1.502
	45		1.662	1.671	1.652		20		1.499	1.501	1.499
1500	1 Hr		1.631	1.650	1.630		36		1.495	1.497	1.495
	10	37A	1.698	1722	1708		41	73A	1.438	1.442	1.432
	20		1672	1702	1692		45		1.440	1.441	1.431
	36		1.591	1.631	1.626		50	15A	1.532	1.543	1.542
	41	73A	1472	1470	1462	1900	5 Hrs.		1.542	1.544	1.542
	45		1472	1464	1460		10	37A	1.491	1.495	1.492
	50	15A	1580	1590	1582		20		1.496	1.491	1.486
1600	2 Hrs		1562	1563	1563		36		1.482	1.486	1.481
	10	37A	1517	1512	1510		41	73A	1.424	1.424	1.422
	20		1.517	1.513	1.510		45		1.425	1.426	1.425
	36		1.513	1.512	1.510		50	15A	1.529	1.531	1.530
	41	73A	1.470	1.460	1.460	2000	6 Hrs.		1.528	1.530	1.530
	45		1.470	1.461	1.460		10	37A	1.475	1.478	1.476
	50	15A	1.551	1.550	1.543		20		1.474	1.476	1.475
1700	3 Hrs		1.551	1.550	1.548		36		1.470	1.472	1.470
	10	37A	1.514	1.511	1.511		41	73A	1.418	1.422	1.415
	20		1.511	1.511	1.510		45		1.420	1.424	1.417
	36		1.510	1.510	1.505		50	15A	1.520	1.526	1.525
	41	73A	1.458	1.458	1.456	2100	7 Hrs		1.518	1.520	1.522
	45		1.451	1.451	1.451		15	73A	1.418	1.419	1.417
HRS./MIN							30		1.422	1.424	1.417
OUTPUT A.H.							45		1.423	1.424	1.416

REMARKS:

2200 8 Hrs.

1.423 1.424 1.411 FORM #YEC-21

# YARDNEY ELECTRIC CORP.

LR 290-1

## DATA SHEET

R/T Lab 197  
Control #278

CHARGE; I<sub>c</sub> 10A-2.05V PROJ. NO. 20413

DISCHARGE; I<sub>a</sub> \_\_\_\_\_ DATE 12/11/72

CELL NO. 1, 2, 3

TESTER E.H., LF. WP WITNESSED A.J.B.

CYCLE NO. 8

REMARKS:

I c 10.0A - 2.05V

/CELL NO.		1	2	3					
INPUT A.M.									
V <sub>F</sub>									
OCV									
START. TIME		1.650	1.651	1.641					
1000	2	1.643	1.645	1.641					
1200	4	1.652	1.937	1.647					
1400	6	1.905	1.903	1.906					
1600	8	1.901	1.901	1.899					
1800	10	1.901	1.902	1.899					
2000	12	1.905	1.905	1.902					
2200	14	1.912	1.913	1.908					
2400	16	1.922	1.921	1.916					
0200	18								
0400	20								
0600	22								
0800	24	1.944	1.945	1.945					
1000	26	1.945	1.944	1.945					
1200	28	1.946	1.946	1.947					
1400	30	1.948	1.949	1.949					
1600	32	1.949	1.950	1.950					
1800	34	1.951	1.960	1.954					
2000	36	2.050	2.050	2.050					
2200	38								
2400	40								
	42								
	44								
	46	1.936	1.945	1.930					
HRS./MIN	→	35.60	34.75	35.5					
OUTPUT A.M.	→	356.0	347.5	355.0					

REMARKS:

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 198  
Control #278

CHARGE; Icc \_\_\_\_\_ PROJ. NO. 20413  
DISCHARGE; Ia See Remarks DATE 12/13/72  
TESTER E.H., LF, Jr., W.P. WITNESSED A.I.B.

CELL NO. 1, 2, 3  
CYCLE NO. 8

REMARKS: The Discharge Profile is as follows:  
Discharge for 8 hr;

367.40 AH out  
each cell.

- 1) 1st hour - 73 amperes
- 2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.
- 3) 8th hour-73 amperes

CELL NO.		I	1	2	3				I	1	2	3
INPUT A.M.												
VP												
OCV			1859	1860	1860							
START. TIME		73A	1765	1751	1761			50	15A	1.549	1.548	1.546
	15		1724	1710	1714		1900	4 hrs		1.549	1.548	1.546
	30		1704	1697	1699			10	37A	1.513	1.510	1.508
	45		1689	1683	1679			20		1.508	1.504	1.503
1600	1 Hr		1.620	1.634	1.621			36		1.502	1.498	1.497
	10	37A	1.668	1.668	1.676			41	73A	1.445	1.441	1.439
	20		1.596	1.626	1.610			45		1.443	1.439	1.438
	36		1.519	1.517	1.516			50	15A	1.541	1.540	1.539
	41	73A	1.480	1.474	1.473		2000	5 Hrs.		1.540	1.538	1.538
	45		1.478	1.473	1.472			10	37A	1.492	1.489	1.488
	50	15A	1.567	1.564	1.566			20		1.486	1.483	1.483
1700	2 Hrs		1.554	1.552	1.552			36		1.482	1.480	1.480
	10	37A	1.524	1.529	1.520			41	73A	1.426	1.424	1.422
	20		1.522	1.519	1.518			45		1.426	1.424	1.422
	36		1.521	1.519	1.517			50	15A	1.528	1.528	1.529
	41	73A	1.480	1.474	1.473		2100	6 Hrs.		1.526	1.526	1.527
	45		1.476	1.471	1.470			10	37A	1.473	1.472	1.473
	50	15A	1.540	1.548	1.547			20		1.470	1.469	1.471
1800	3 Hrs		1.552	1.551	1.550			36		1.465	1.465	1.467
	10	37A	1.521	1.518	1.516			41	73A	1.413	1.412	1.410
	20		1.519	1.516	1.515			45		1.416	1.414	1.412
	36		1.517	1.514	1.512			50	15A	1.515	1.515	1.519
	41	73A					2200	7 Hrs		1.514	1.513	1.518
	45		1.463	1.462	1.466			15	73A	1.416	1.414	1.410
HRS./MIN								30		1.416	1.414	1.408
OUTPUT A.M.								45		1.415	1.410	1.402

REMARKS:

2300 8 Hrs.

1.410 1.400 1.389

FORM #YEC-20

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 200  
Control #278

CHARGE; I<sub>ch</sub> \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; I<sub>d</sub> See Remarks DATE 12/15/72

CELL NO. 1, 2, 3

TESTER E.H. LF, Jr., W.P. WITNESSED S.J.B.

CYCLE NO. 9

REMARKS: The Discharge Profile is as follows:  
Discharge for 8 hr;

367.40 AH out  
ach cell.

- 1) 1st hour - 73 amperes
- 2) 2nd-7th hour-36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.
- 3) 8th hour-73 amperes

CELL NO.		I	1	2	3				I	1	2	3
INPUT A.H.												
V <sub>F</sub>												
OCV			1861	1860	1865							
START. TIME		73A	1769	1760	1768			50	15A	1549	1547	1547
	15		1737	1728	1729	1800	4 hrs			1549	1546	1546
	30		1721	1713	1704			10	37A	1512	1506	1507
	45		1707	1701	1698			20		1507	1500	1501
1500	1 Hr		1655	1652	1663			36		1502	1496	1497
	10	37A	1.606	1.604	1.717			47	73A	1444	1438	1437
	20		1631	1606	1672			45		1441	1435	1434
	36		1519	1517	1514			50	15A	1540	1538	1539
	41	73A	1479	1475	1470	1900	5 Hrs.			1539	1536	1537
	45		1478	1474	1469			10	37A	1490	1485	1487
	50	15A	1552	1555	1558			20		1486	1481	1483
1600	2 Hrs		1552	1551	1549			36		1480	1476	1480
	10	37A	1522	1520	1516			41	73A	1427	1424	1423
	20		1.521	1.519	1.515			45		1426	1423	1422
	36		1.521	1.518	1.515			50	15A	1527	1525	1529
	41	73A	1476	1470	1468	2000	6 Hrs.			1524	1521	1526
	45		1474	1468	1466			10	37A	1474	1471	1475
	50	15A	1553	1551	1549			20		1470	1467	1472
1700	3 Hrs		1552	1550	1549			36		1465	1463	1469
	10	37A	1520	1516	1515			41	73A	1426	1424	1424
	20		1518	1514	1513			45		1426	1424	1423
	36		1515	1509	1509			50	15A	1516	1514	1520
	41	73A	1464	1455	1455	2100	7 Hrs			1512	1509	1517
	45		1460	1451	1452			15	73A	1418	1414	1410
HRS./MIN								30		1416	1410	1405
OUTPUT A.H.								45		1414	1400	1396

REMARKS:

2200 8 Hrs.

1400 1354

FORM #YEC-21  
1958

# YARDNEY ELECTRIC CORP.

LR290-1

## DATA SHEET

R/T Lab 202  
Control #278

CHARGE; Icc \_\_\_\_\_ PROJ. NO. 20413

DISCHARGE; Ia See Remarks DATE 12/20/72

CELL NO. 1, 2, 3

TESTER L.F., Jr., E.H., W.P. WITNESSED L.J.B.

CYCLE NO. 10

REMARKS: The Discharge Profile is as follows:  
Discharge for 8 hr;

- 1) 1st hour - 73 amperes
- 2) 2nd-7th hour - 36 min. at 37 amps, 9 min. at 73 amps, 15 min. at 15 amps.
- 3) 8th hour - 73 amperes

367.40 AH out  
each cell.

CELL NO.		I	1	2	3				I	1	2	3
INPUT A.H.												
VF												
OCV			1850	1850	1860							
START. TIME		73A	1.770	1.762	1.765			50	15A	1.547	1.545	1.544
	15		1730	1773	1.717	1800	4 hrs.			1.548	1.545	1.545
	30		1.709	1.702	1.691			10	37A	1.507	1.501	1.501
	45		1.694	1.685	1.683			20		1.504	1.497	1.498
1500	1 Hr.		1.612	1.575	1.619			36		1.498	1.493	1.494
	10	37A	1.622	1.544	1.654			41	73A	1.441	1.435	1.435
	20		1.520	1.517	1.550			45		1.438	1.434	1.434
	36		1519	1518	1513			50	15A	1.538	1.535	1.538
	41	73A	1480	1476	1472	1900	5 Hrs.			1.537	1.534	1.536
	45		1477	1473	1469			10	37A	1.490	1.485	1.489
	50	15A	1.559	1.555	1.556			20		1.485	1.481	1.485
1600	2 Hrs		1.552	1.551	1.549			36		1.481	1.477	1.482
	10	37A	1.524	1.523	1.519			41	73A	1.426	1.423	1.424
	20		1521	1519	1516			45		1.425	1.423	1.424
	36		1.520	1.517	1.514			50	15A	1.528	1.526	1.531
	41	73A	1.477	1.472	1.468	2000	6 Hrs.			1.524	1.521	1.528
	45		1.474	1.468	1.464			10	37A	1.474	1.471	1.476
	50	15A	1.552	1.550	1.549			20		1.470	1.468	1.474
1700	3 Hrs		1.552	1.550	1.549			36		1.465	1.463	1.470
	10	37A	1.519	1.515	1.513			41	73A	1.414	1.412	1.412
	20		1.516	1.512	1.510			45		1.416	1.414	1.413
	36		1.514	1.508	1.507			50	15A	1.516	1.515	1.522
	41	73A	1.460	1.452	1.450	2100	7 Hrs			1.513	1.511	1.520
	45		1.459	1.450	1.448			15	73A	1.414	1.412	1.409
HRS./MIN								30		1.414	1.405	1.404
OUTPUT A.H.								45		1.404	1.375	1.383

REMARKS:

2200 8 Hrs. 1.388 1.009 FORM # YEC-20  
1.325

APPENDIX E

FAST CHARGING OF SILVER-ZINC BATTERIES

Fast Charging of  
Silver-Zinc Batteries

FINAL REPORT

Prepared for: Mine Safety Appliances Company  
R. D. 2  
Evans City, Pennsylvania 16033

Attention: Mr. E. J. Hohos

Prepared by

  
Russell R. Pellmann

Approved by

  
Albert E. Ketler

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## FAST CHARGING OF SILVER-ZINC BATTERIES

### 1. INTRODUCTION

An Emergency Mine Rescue Vehicle containing its own power source of silver-zinc secondary batteries is being developed for operation over an eight-hour period. After a prescribed operation period, the battery will be discharged. For continuous vehicle operation, it will be replaced with a second battery. The discharged battery must then be recharged and made ready for use within the next eight-hour period.

The selected battery, consisting of 24 series-connected Yardney LR290 cells, is designed to satisfy the discharge energy requirements. Tests on three cells have verified the required capacity of 370 ampere-hours after 10 cycles. The present charge technique requires 40 hours. Faster charging is desirable in order to minimize the number of standby batteries. For this reason, Mine Safety Appliances Company requested Ocean Energy to examine fast charging techniques and the capability of the LR290 to accept a full charge within a five- to eight-hour period. If possible, the charge time shall be compatible with the discharge time which results in a system requiring only one standby battery per vehicle.

This report contains the technical data and analysis to support the conclusions and recommendations stated in the summary.

### 2. SUMMARY

Silver-zinc cells in a secondary battery configuration are very sensitive to charging technique. The most used charging approach is to charge at a current rate not exceeding 15 - 20 milliamperes per square inch of plate area. For the LR290, this level is 10 amperes. A standard charger having current limiting satisfies the above charge limit criteria. Voltage limiting and termination is necessary to prevent excess overcharge. At the prescribed charge rate and energy requirements, the LR290 requires 40 hours for full charge. This long charge time is not compatible with mission requirements and faster charging is essential to the success of the program.

Other unusual charge methods were examined during the course of this study. These include fast DC, pulse, and AC techniques.

The fast DC charging technique uses the previously established charge criteria of 15 - 20 ma/in<sup>2</sup> which requires a cell redesign. The LR290 redesigned with sufficient plate area for this fast charge is designated the LR370 by Yardney. A nonstandard charger is required to supply the higher DC charge current and other controls. Further, the fast DC charge may not achieve full 100% cell capacity in an eight-hour period because a subsequent low rate finishing charge is normally required.

The pulse charge technique periodically applies a high current pulse up to 200 milliamperes per square inch and allows an off period for cell electrolyte equalization. Cell redesign is not required, but the pulse charger is much more complex than the charger for fast DC charge technique.

The AC charging method is also a pulse charge type; however, a periodic discharge pulse is included in the overall charging cycle. The charger design is slightly more complex than that for the pulse charge technique. Both the pulse and AC charge techniques significantly extend the useful operating life compared with expected rapid degradation with the steady-state fast DC charge.

All of these fast charging methods require a test program to verify the charger/cell compatibility. Each will charge the battery within a five to eight-hour period and will, therefore, satisfy mission requirements. Pulse or AC charging techniques hold the best promise for the five-hour charge duration for maximum battery life and without cell size changes. The advantages are:

1. Cell redesign is not required.
2. Vehicle redesign is not required.
3. Activation time may be reduced if AC charging is used.
4. Battery temperature rise is acceptable.
5. High cycle life.

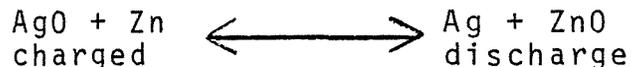
### 3. TECHNICAL DISCUSSION

Capacity of the LR290 cell was established by testing at Yardney Electric Company. Cycle tests were performed on three cells using the mission power profile supplied by MSA, and test data are tabulated in Yardney Report No. 1581-22. The charge level was at the recommended 10-amp level with charge durations of about 40 hours. The desired five- to eight-hour charge duration objective requires an average charge current of 74 to 46 amperes respectively. The initial conclusion is that the LR290 cannot be charged at that rate without serious loss of cycle capability and capacity.

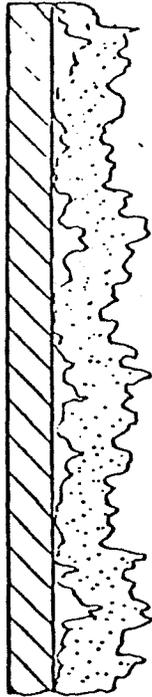
Recent research and application experience on other types of cells have suggested charge techniques which show excellent promise of reducing the charge duration of silver-zinc batteries. These concepts are reviewed in detail and specific evaluations made to determine whether the presently designed LR290 can be charged this fast.

#### CELL PHYSICS

The discharge reaction of the silver-zinc cell results in a transfer of zinc to the electrolyte. The general reaction is:



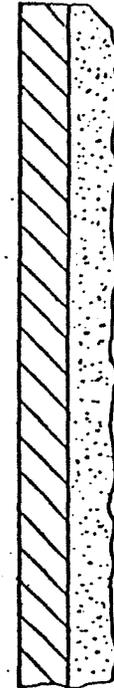
During charge, the zinc is redeposited on the zinc plates in the form of dendrites. The particular form of this dendrite is a function of charge rate. At low charge rates the dendrite is mossy. At high charge rates the dendrite is crystalline. The mossy dendrite occurs over the whole plate area and does not adhere well to the plate structure. As a result, over many charge/discharge cycles, the capacity gradually decreases due to increasing internal resistance. Cell life under this degradation mode is quite predictable and well known as a typical capacity/life characteristic. Under faster charging, the crystalline dendrite generates a strong bond between the plate structure and the redeposited zinc. Concentrations of these dendrites occur in regions where excess electrolyte is located and usually results in whisker growth and eventual penetration of the separator. Cell life may abruptly and unpredictably end due to internal short circuits.



Normal DC Charge  
25.8 ma/sq. in.



Fast DC Charge  
250 ma/sq. in.  
116 coulombs per sq. in.



Pulse Charge  
250 ma/sq. in.  
387 coulombs per sq. in.

Figure 1 - Typical Comparative Profile  
of Mossy, Crystalline, and Controlled Crystalline  
Dendrite Zinc Redeposition

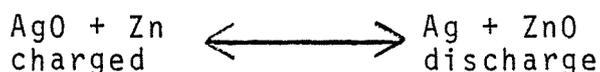
### 3. TECHNICAL DISCUSSION

Capacity of the LR290 cell was established by testing at Yardney Electric Company. Cycle tests were performed on three cells using the mission power profile supplied by MSA, and test data are tabulated in Yardney Report No. 1581-22. The charge level was at the recommended 10-amp level with charge durations of about 40 hours. The desired five- to eight-hour charge duration objective requires an average charge current of 74 to 46 amperes respectively. The initial conclusion is that the LR290 cannot be charged at that rate without serious loss of cycle capability and capacity.

Recent research and application experience on other types of cells have suggested charge techniques which show excellent promise of reducing the charge duration of silver-zinc batteries. These concepts are reviewed in detail and specific evaluations made to determine whether the presently designed LR290 can be charged this fast.

#### CELL PHYSICS

The discharge reaction of the silver-zinc cell results in a transfer of zinc to the electrolyte. The general reaction is:



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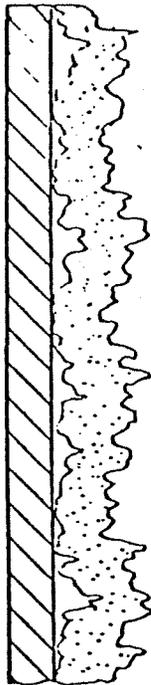
The dendrite formations described above occur under continuous DC charge conditions. If a high rate charge were periodically terminated to allow the electrolyte to redistribute, the crystalline dendrite form changes from a few high whiskers to a large number of shallow whiskers. The dendrite growth is thereby controlled so that the cell may be charged at a higher rate without the usual decrease in cycle life or capacity. Figure 1 shows a typical comparative profile of mossy, crystalline, and controlled crystalline dendrite zinc redeposition.

A conclusion is that pulse charging is an important new method for fast charging that offers additional cell life along with reduced charging duration. The specific design parameters of on and off periods, frequency, current levels, etc., are based on experience from others. Although this information is incomplete, we are convinced of its authenticity through cross-confirmation of independent authorities.

#### CHARGE TECHNIQUES

Normal DC Charging - Manufacturers generally recommend a charge rate based on a constant current charge until the battery voltage reaches 2.00 volts per cell. The charge is then terminated. For typical cells, the charge current is 15 - 20 milliamperes per square inch of plate area. Cells charged in this manner tend to degrade in an accelerated but predictable manner to about one-half initial capacity at end of life. If high cycle life is required, the number of series-connected cells becomes a critical consideration since the individual cells differ somewhat in their charge acceptance, capacity, and other characteristics.

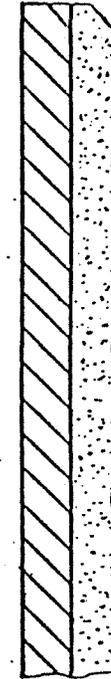
Fast DC Charging - This charge concept is similar to the normal DC charge except that a higher current is used. The charge current density stated above -- 15 to 20 ma/sq in. -- remains unchanged; however, a larger number of thinner plates is used to provide the greater plate area within the same volume. For a charge duration of five hours and a discharge of 370 ampere hours, a charge current of 74 amperes is required. For an eight-hour charge, 46 amperes would be required. Present practice, however, usually specifies a finishing charge at a lower current level, because the cell does not accept a full 100% charge at the high current rate. The additional time-current levels are determined by test. Both ESB and Yardney manufacture cells to accept this type of fast charge. Yardney has proposed the LR370 cell, a redesign that will accept the 46 ampere, eight-hour rate. Additional time may be required for the finishing charge.



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Pulse Charging - Pulse charging is a charge method derived from attempts to increase cycle life while fast charging through a method of zinc plate forming that decreases plate resistance and reduces penetration of the separator. The approach has been used on other typical silver-zinc cells. The general design guidelines are:

- a. Pulse duration of 10 to 200 milliseconds. (The on time should be as short as possible.)
- b. The off period as long as possible (50% off time is a minimum).
- c. Current density from 100 to 300 ma/sq in. of plate surface area.
- d. Charge termination is determined by experiment for each battery system.

AC Charging - AC charging is similar to the pulse-charging method but with the addition of a high current discharge pulse which is applied briefly following the normal off period. Since the cell experiences a plus and minus current flow, the charge method is referred to as AC charging. The physical phenomenon occurring is not well understood; however, it is believed that the regions where high crystalline dendrites occur tend to have lower local impedance. Discharging at a high current level for the very short period reduces the dendrite size, and further reduces the likelihood that large zinc dendrites will form and penetrate the separator. The silver plate is also improved in form. The same pulse charge criteria applies to this charge method. The magnitude of the discharge pulse can be up to one-half the magnitude of the charge pulse, but the duration possibly ranging from 10 to 50% of the charge pulse.

Charge termination and magnitude of discharge pulse must be determined by experiment. Since the necessity of the discharge pulse is not known for certain at this time (in terms of capacity and cycle life), a comparison of pulse and AC charging should be made by test to fully evaluate the concept.

One additional benefit of both types of pulse charging has been observed. When the cell is initially filled, a long soak time is usually required to fully wet the plates. AC charging causes the plates to wet more rapidly so that soak time is greatly reduced. This may be explained in part that on discharge, the electrolyte is drawn into the plates which forces wetting. Thus, wetting action can also take place during charge

as well as discharge periods which results in full cell capacity without the usual long soak period. This may be important if cells are stored in dry/charged condition prior to use.

#### EXAMPLES OF CHARGING TECHNIQUES

Normal DC Charging - Ocean Energy has been active in the design and fabrication of silver-zinc battery chargers for operation within the charge limits established by the manufacturer and specific requirements of the energy system. The concept of charge termination used by Ocean Energy is unique in that the charger output voltage is not removed completely. The output is transferred to the precise open circuit voltage of the battery -- 1.87 volts per cell -- so that the cells will remain in a fully charged state until it is ready for discharge. This charge concept is a two voltage-level charger and has been proven safe and reliable. The advantage is the elimination of loss of charge (self-discharge) due to long standby service.

Fast DC Charging - Except for certain cell responses that appear at higher charge current rates, fast DC charging is similar in function to the normal charge method. As such, the charger design approach is similar. The two-step voltage charger circuits are also applicable to the two-step current charger which will be required for this fast charger. Ocean Energy has experience with both voltage and current controlled chargers.

Pulse Charging and AC Charging - Pulse charging has been applied for some time to nickel-cadmium and lead-acid batteries and, to a lesser degree, to silver-zinc batteries. Most silver-zinc work has been in the evaluation of couples and low capacity cells. All indications are that pulse charging will result in better formed plates.

One example of a system now being used has the following design guidelines:

1. Yardney LR3/10, 10 ampere hours cell.
2. Depth of discharge is 100%.
3. On time is 200 milliseconds at 10 ampere charge rate.
4. Off time is 200 milliseconds.
5. Plate area is 26.5 square inches.
6. Charge current density about 191 ma/sq in.

The present systems have been operating for about six months and the user reports good results. No information is available on number of cycles per battery. Initially the system used LR3/5, 5 ampere hours cells, but failures occurred early in life. This represents a current density of 380 ma/sq in., and is in excess of the established guideline of 300 ma/sq in. arrived at independently by another source.

Another example performed by NASA-Goddard for cell evaluation had the following operation conditions:

1. Yardney cells, 16 ampere hours (HR16S-1).
2. Initial capacity is 21 ampere hours.
3. Capacity at end of 200 cycles is 16 ampere hours.
4. Depth of discharge is 35%.
5. On time is 5 seconds at 48 amperes.
6. Off time is 10 seconds.
7. Forty-eight cycles per day.
8. Eight hundred seventy-five total cycles.

Some observations were:

No capacity was lost which was different from normal charge method. It was estimated that after 875 cycles the capacity was about 25% higher than would have occurred under normal DC charging. No appreciable temperature rise was noticed and no pressure build-up occurred. Charge termination was determined experimentally at 2.1 volts per cell.

Another example of pulse charging was performed by Jet Propulsion Laboratory on another manufacturer's cells. These tests resulted in good zinc deposits but the silver penetrated the separator rapidly which resulted in low cycle life. Further evaluations were not made; however, it is believed that the Yardney silvered separator (referenced C-19) would not have allowed the silver migration which caused the premature failure. The first example substantiates this conclusion. It appears that Yardney Electric Company is a superior supplier for batteries which respond favorably to pulse charging. The C-19 separator seems to be responsible for this proprietary edge over competitors' batteries.

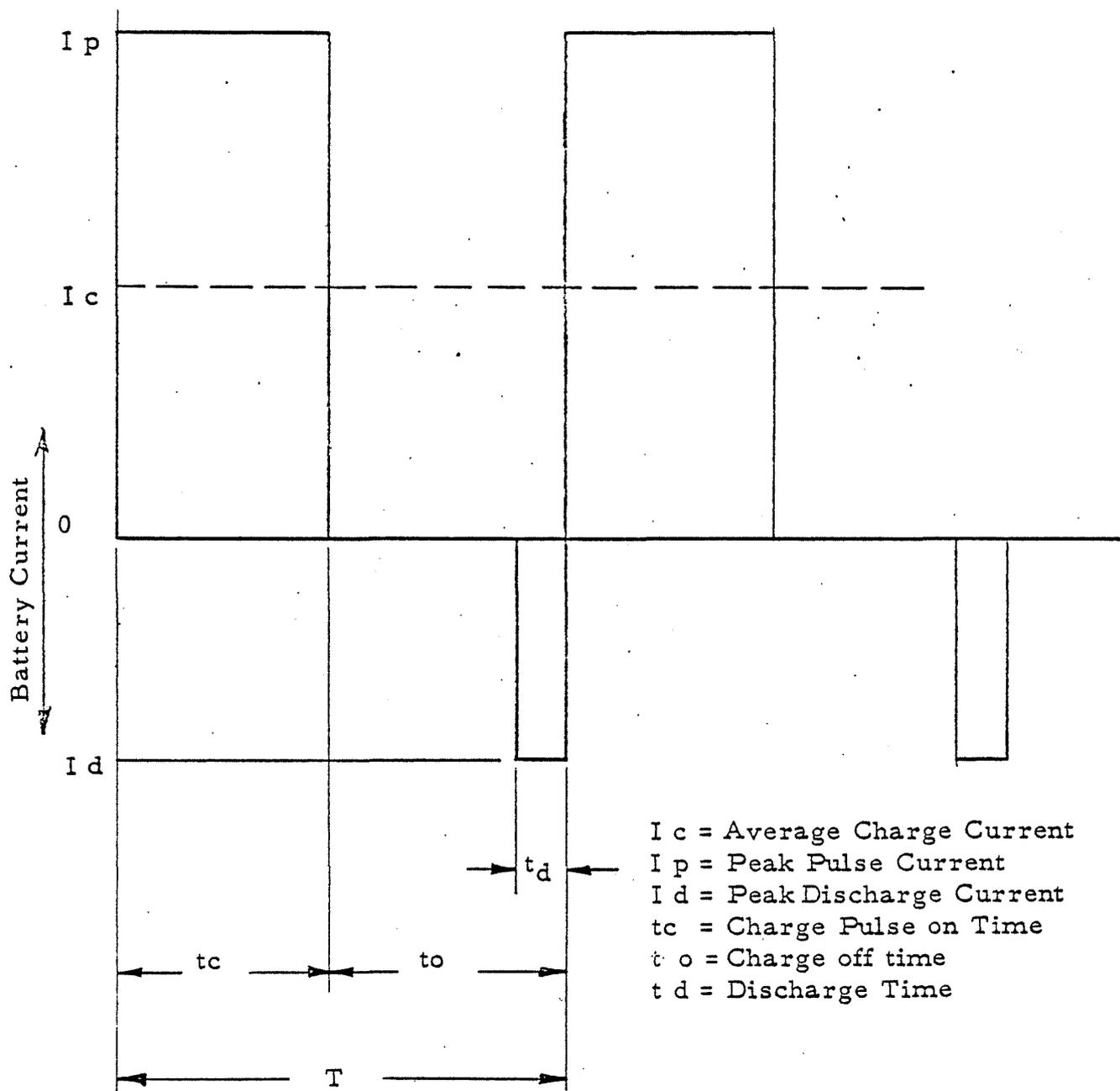
An example of AC charging was noted in a recent Russian report. This study was aimed at determining the effects of AC charging on performance after activation and to develop methods for improving electro-deposition of plates. A soak time of 72 hours was generally required to thoroughly wet the plates. If this time could be reduced, the silver-zinc battery would be more suitable for certain applications.

The experiments reported compared both AC and DC charge concepts. Capacity measurements were made after each charge cycle. The AC charge method produced a high initial capacity; however, after five cycles, the capacity resulting from the DC charge method approached the capacity attained by AC charging. Tests were continued on the same battery in a sequence of three AC charge cycles and three DC charge cycles. Each time the AC charge method was used the capacity increased by 15%. Conclusions reached were that AC charging allows rapid use of batteries after activation and that a higher initial capacity is attainable without long soak periods. Both pulse and AC chargers involve new concepts for charging silver-zinc batteries. Hardware (charger design and development) is required and testing of the batteries with the chargers is essential.

#### LR290 CELL EVALUATION

Based on experience and examples gathered from many sources, both the pulse and AC charging techniques should be considered for the LR290 cell. The basic cell parameters are plate area and type of separator. Since the LR290 contains the C-19 separator, the plate area is the only other limiting parameter. Based upon a plate area of 672 square inches for this cell, the general guidelines for current density of 100 - 300 ma/sq in. yields a charge current range of 67.2 - 201.6 amperes. Further, if the cell has a capacity of 370 ampere hours and a charge efficiency is high (say 95%) the charge time ranges from 5.7 to 1.93 hours. Using the data point of 190 ma/sq in. from example one, the nominal charge current is 128 amperes and the charge time is three hours. This time period is sufficiently lower than the five-hour objective allowing for a longer off period than 50% which is beneficial for pulse charging. It also allows a margin for a discharge pulse for AC charging.

Figure 2 shows relationships between time and charge currents. Based upon the average current requirements, it is simple to derive the required magnitudes of peak currents, on time and off time.



$$(I_p - I_c) t_c - I_d t_d = I_c (t_o - t_d)$$

Figure 2 - Pulse Charge Profile

Both pulse and AC charging permit the LR290 to be charged within the specified five- to eight-hour objective. With only one example of AC charging, it is not conclusive that the discharge pulse is actually required. Advantages are observed with other alkaline cells, however, and the AC theory appears sound. Since it is not difficult to incorporate the discharge pulse in conjunction with the pulse charger, the possible advantages of AC charging should be evaluated for this important silver-zinc battery application.

#### 4. TEST PROGRAM

Three cells have been evaluated by Yardney under normal DC charging (40 hours duration). These cells could be further tested in a pulse charge method to determine cell performance using pulse chargers having the characteristics described herein. The program would allow for one cycle per day. Within a relatively short time period the concepts could be evaluated and recommendations made for further development of the pulse charger system.