PROPER BATTERY SYSTEM DESIGN FOR GAS EXPERIMENTS

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ABSTRACT

The purpose of this paper is to help the GAS experimenter to design a battery system that meets mission success requirements while at the same time reducing the hazards associated with the battery system. Lead-acid, silver-zinc and alkaline chemistry batteries will be discussed. Lithium batteries will be briefly discussed with emphasis on back-up power supply capabilities. The hazards associated with different battery configurations will be discussed along with the controls necessary to make the battery system two-fault tolerant.

INTRODUCTION

The purpose of this paper is to discuss proper battery system design for experiments utilizing the Get Away Special (GAS) carrier system. The safety associated with the battery system will be the main point of discussion.

Before the battery system can be designed, the experiment requirements must be determined. After a full analysis of the objectives and purpose of the experiment, the designer must transform the design into concrete numbers. The first requirement will be the expected working voltage. The experimenter has a number of choices in this regard. In most cases, the experimenter will determine the voltage necessary to run most of the experiment's components and will use DC/DC convertors to operate other unique devices. The experimenter may also use two battery packs to independently operate different parts of the experiment. For example, one 5-volt battery pack could be used to operate the computer while a second 24-volt battery pack could be used to operate the rest of the experiment.

Other factors that must be determined are the maximum current draw and expected duration of the experiment. The maximum current draw and expected duration are needed in order to choose the proper fuse size and the proper battery type.

FUSE SIZE

The fuses used for the battery must be sized to protect the main power wires and the battery itself. After the maximum current draw has been determined, the experimenter should include a reliability factor to that number. Most designers will derate the system by 50%. For example, if the maximum current draw is 5 amps, a fuse size of 10 amps will be chosen. Based on the application, the designer must determine whether to use a fast-blow or slow-blow fuse. The main difference between these two types is that slow-blow fuses can withstand high instantaneous currents. Most GAS experimenters use fast-blow fuses.

The designer should also fuse all major components. The purpose for fusing major components (motors, actuators, heaters, etc.) is to protect the device from overheating. Most designers fuse major components for mission success purposes also.

WIRE SIZE

The wire size is determined from the fuse size. The wire size must be determined based on the gage of the wire and the thermal rating of the insulation. Most experiments use Teflon insulated wire with a thermal rating of 200°C. Some experimenters have also used Kapton insulated wire. It should be noted that PVC insulated wire is not acceptable because PVC is a high outgasser.

The maximum current rating for wire on the ground is different for space since there is no convective heat loss in space. In TABLE I, NASA has determined maximum current dissipation for three insulation ratings (150°C, 175°C and 200°) and for both space and ground (S/G). For example, the maximum current that a 12 gage, 200°C wire can dissipate before overheating in space is 38 amps as compared to 74 amps on ground. Consequently, the space rating must be considered when wire size is determined.

TABLE I - WIRE RATING FOR SPACE AND GROUND

WIRE GAGE	CURRENT RATING (AMPS)			WIRE GAGE	CURRENT RATING (AMPS)		
	WIRE RATING (S/G)				WIRE RATING (S/G)		
	150°C	175°C	200°C		150°C	175°C	200°C
0	235/369	285/405	340/450	14	19/56	23/62	26/65
2	155/270	190/300	215/340	16	14/39	17/42	20/45
4	115/220	140/250	160/280	18	13/37	15/39	17/42
6	85/170	100/180	120/190	20	8/25	10/27	12/29
8	60/120	71/130	80/150	22	6/19	8/20	9/22
10	37/80	42/90	51/100	24	5/14	7/15	8/16
12	29/62	34/68	38/74	26	4/13	5/14	6/15

Reproduced from NSTS 18798A, ER-87-326

The fuse selection criteria is based on the maximum continuous overload rather than the dead short condition. The rating is based on the amount of current that the fuse can handle for approximately 10 to 15 minutes before actually blowing. This is determined by extrapolating the fuse current versus time graph until it levels off (usually 10 to 15 minutes). For fast-blow fuses this tends to be approximately 1.35 times the dead short rating. For slow-blow fuses this tends to be approximately 2.4 times the dead short rating. For example, a 10 amp fast-blow fuse could possibly be overloaded to 13.50 amps before blowing. This maximum continuous overload rating must be used to determine the minimum wire size. For example, 18 gage wire rated at 200°C would be the minimum needed for the above 10 amp fuse. If the equivalent slow blow fuse was used, the minimum wire size would be 14 gage rated at 200°C.

The designer must also protect all wires when going from a higher gage wire to multiple lower gage wires. The lower gage wires must be protected such that if one of the other wires is lost, excess current will not overload the surviving wire. For example, a design may call for a 12 gage wire to be distributed to two 14 gage wires. If the main fuse size is 25 amps, both wires together could easily handle this load. However, if one of the wires open-circuited, the other wire could see approximately 33 amps. For this reason, it would be necessary to fuse each wire to 15 amps.

Finally, the designer must be cognizant of educated (smart) shorts. Educated shorts arise when three or more bus wires are used to distribute current over several smaller wires (see Figure 1). If each bus line is fused at the first bus junction, it is possible for one of the wires to overheat if a short occurs after the fuse and the short is such that it does not cause the bus fuse to blow. The designer must either place a fuse before the bus to protect the smallest wire in the bus or fuses must be placed at both ends of the bus.
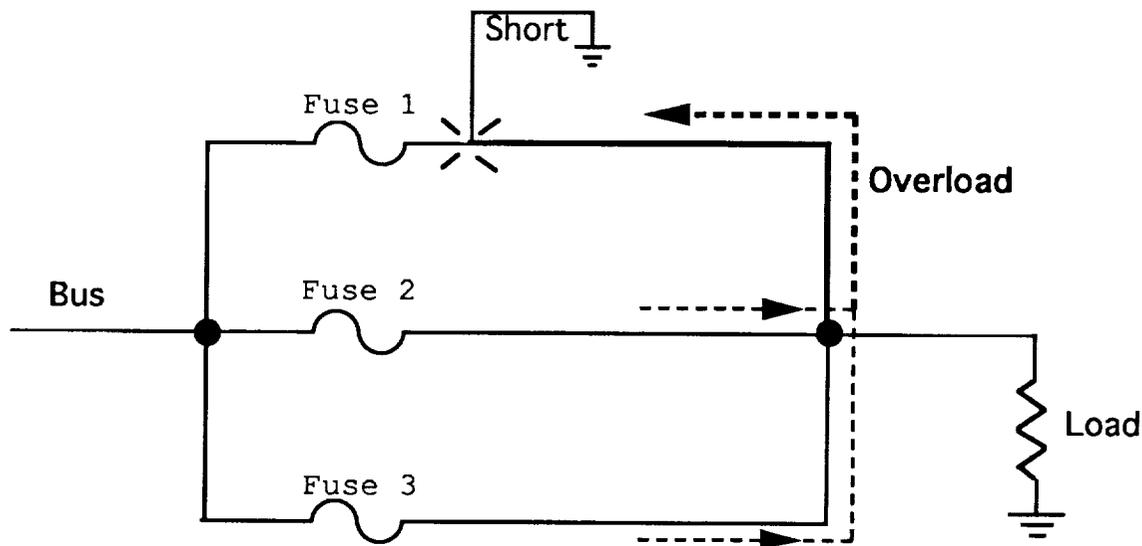

FIGURE 1 - EDUCATED SHORT

BATTERY TYPE

There are three types of batteries that are commonly used in GAS: Alkaline cells, Lead-acid cells, and Silver zinc cells. There are many advantages and disadvantages to each cell but cost seems to drive most decisions. Silver zinc cells tend to be quite expensive while alkaline cells are the cheapest. Regardless of which type of cell is chosen, there are some important guidelines that should be followed. The first factor to consider is the expected duration of the experiment. If the experiment is expected to run for 10 hours at a rate of 1 amp, the capacity of the cell/battery should be at least 10 amp-hours. However, the designer also needs to consider self-discharging between integration and launch (approximately three to four months). Finally, the expected operating temperature must be considered since battery performance varies significantly with temperature.

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After the cell type has been chosen, the experimenter will set the voltage by placing the necessary complement of cells in series. In terms of capacity, the experimenter will probably have to decide whether to use parallel cell strings to increase capacity or to use a higher capacity cell. In most circumstances, it is cheaper, more efficient, and safer to use the higher capacity cell. When cell strings are placed in parallel, they must be protected against cell reversal. In order to control this hazard, it is necessary to diode or double diode isolate each parallel cell string. The diodes reduce the voltage output by approximately .7 volts due to the turn-on voltage of a standard diode. The designer may use Schottky diodes whose turn-on voltage is approximately .3 volts or it may be necessary to add an additional cell in series with each string to compensate for the diode voltage drop. In addition, parallel cell strings will not discharge as evenly and completely as compared to a higher capacity cell.

BATTERY BOX

The main batteries must be enclosed within a battery box. In general, all battery boxes must contain the following:

1. All interior surfaces of the battery box must be coated with a non-conductive, electrolyte resistant material.

2. All cells need to be firmly secured in order to prevent vibration damage to the cells.

3. The interior of the box should contain absorbent material.

4. If the box is constructed of a conductive material (aluminum), then the battery fuses must be placed inside the box.

The designer must also determine whether to vent the battery box to the canister or outside the canister to the cargo bay. Silver zinc batteries have always been vented to the cargo bay while lead-acid and alkaline batteries have been vented to the cargo on a case by case basis. If the battery box is vented to the cargo bay, then the box must be air-tight and the integrity of the seal verified. Most experimenters perform a leak test by pressurizing the box to 22.5 psia for 24 hours. There should be no pressure drop during this period. The experimenter will also have to provide the plumbing to the NASA pressure relief valves as stated on page 20 of the GAS Experimenter Handbook.

If the experimenter elects to vent the battery to the inside of the GAS canister, a free volume analysis must be performed. The experimenter will have to determine the amount of gas that can be evolved under worst case conditions. The data should include a standing test, cell reversal test, and a short circuit test. Using this data the experimenter can calculate whether the evolved gas will generate a combustible atmosphere in the free volume of the canister.

NASA INTERFACE

Another consideration in the battery system design is the connection to the NASA/GAS interface. As a policy, NASA must have control over the experimenter's power. In most cases this is accomplished by routing the battery supply through Relay A of the GAS Control Decoder (GCD). Relay A controls the Payload Power Contactor (PPC). The PPC contains a pair of series redundant contacts each rated at 25 amps as shown in Figure 2. This configuration gives the experimenter two options in which to route the power system. The first option is to bus the power through Circuit 1 and Circuit 2. This gives the experimenter a redundant path for the power system (see Figure 3). However, the maximum current cannot be greater than 25 amps in case one of the lines fail. If there are two independent sources, another option is to route each source through a separate circuit (see Figure 4). In this case, each circuit is limited to 25 amps.

The PPC also contains two malfunction inputs. These inputs can be used to shut the power off in case there is a malfunction (overtemperature, motor overspeed, low battery voltage, etc.). If there is a malfunction, the PPC will turn the power off and will attempt to reapply power at regular intervals until the malfunction no longer exists or until Relay A is switched to latent. It should be noted that the malfunction inputs can only be used for mission success purposes and cannot be used to control any safety hazard. Finally, external power may be applied to the experiment through the PPC during integration.

The experimenter may also use GCD Relays B and C. These relays are rated at 2 amps maximum. Most experimenters use these relays to provide signals to the experiment. A relay may be used to command a certain experiment to start during an astronaut sleep period or it could be used as a time mark for data collection purposes.

BACKUP BATTERY

The next consideration for the designer are back-up batteries. Back-up batteries are normally used to maintain memory or other data collection devices after the main power has been turned off. The experimenter may choose any battery type but special care should be taken if lithium button cells are used. Lithium cells can be a safety hazard because of the high energy capacity of these cells. If the design calls for lithium cells, the experimenter must include detailed information on the chemistry of the lithium cell, the power requirements, and the size of the cell. In addition, the lithium cell will need to be protected. The circuit should be diode isolated and fused, or the circuit should be double diode isolated (see Figure 5). These controls are meant to protect the lithium cell from being charged by the main power supply. Other cell chemistries are preferred over lithium since the safety risks are much lower.
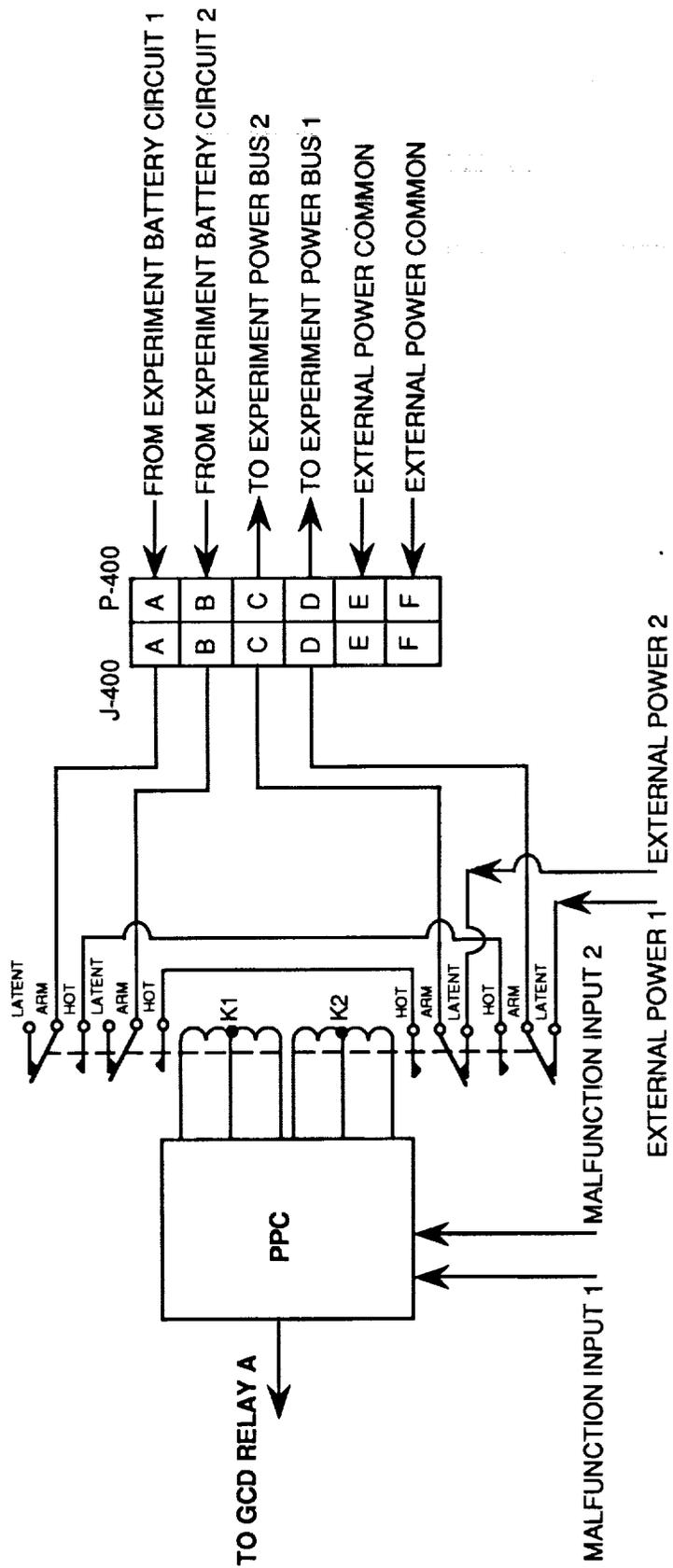
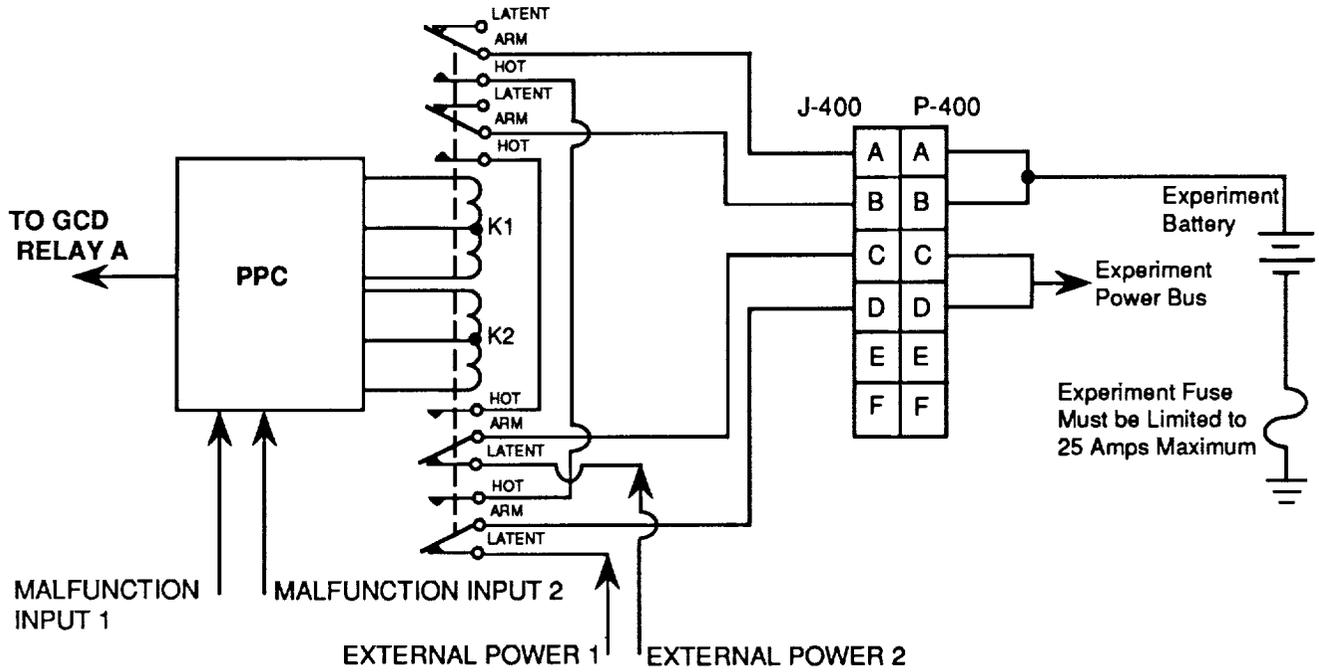**FIGURE 2 - PAYLOAD POWER CONTACTOR (PPC)**
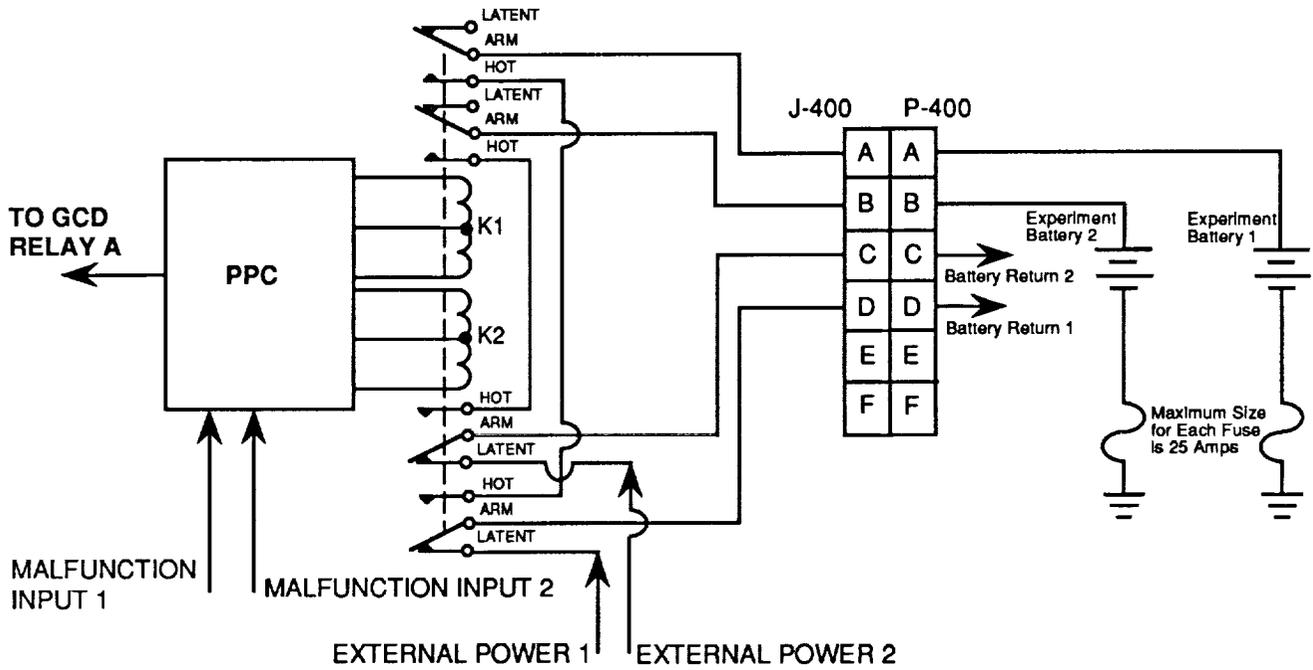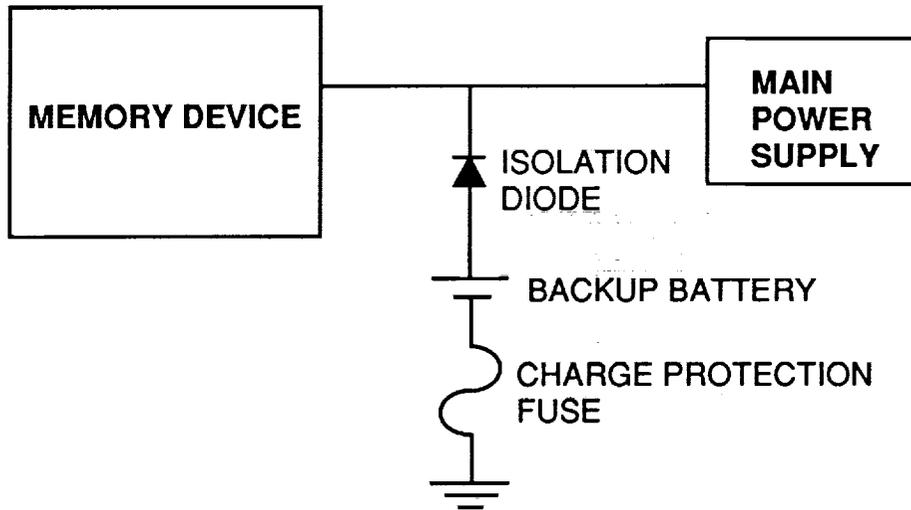
FIGURE 3 - REDUNDANT USE OF PPC
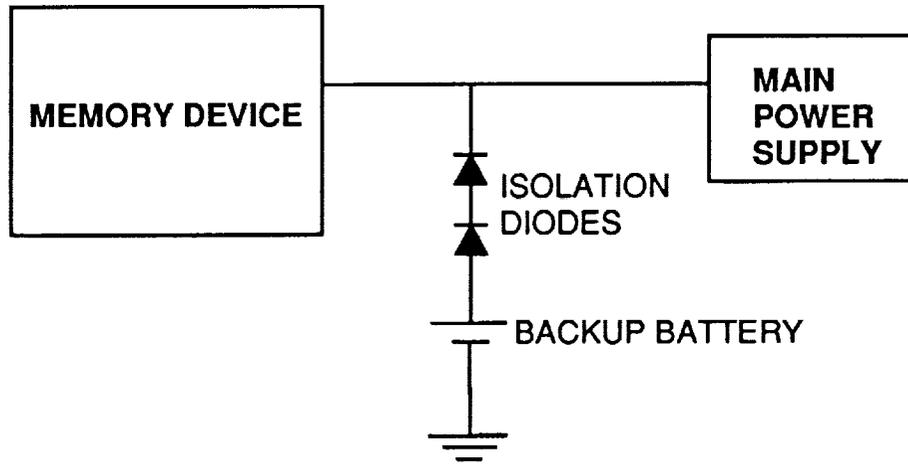

FIGURE 4 - DUAL POWER SUPPLIES

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MEMORY DEVICE

MAIN POWER SUPPLY

ISOLATION DIODE

BACKUP BATTERY

CHARGE PROTECTION FUSE

DIODE ISOLATED AND FUSED

MEMORY DEVICE

MAIN POWER SUPPLY

ISOLATION DIODES

BACKUP BATTERY

DOUBLE DIODE ISOLATED

FIGURE 5 - PROTECTION OF LITHIUM BACKUP BATTERIES

SAFETY SUMMARY

The foregoing discussion should cover most of the safety related hazards associated with the battery system. The following is a summary of the controls needed in every battery system:

Fusing

1. The main fuses protect the battery from an overcurrent condition. An overcurrent condition is discharging the battery higher than the maximum rate. In most experiments, this should never be a problem.

2. The fuses are sized to protect the wires from overheating.

3. The fuses must be placed on the ground leg of the battery, and within any conductive battery box.

Diode Isolation

4. All parallel cell strings must be diode isolated to prevent reverse charging due to cell reversal.

5. Back-up lithium cells must be double diode isolated, or diode isolated and fused in order to prevent charging from the main power supply.

Battery Box

6. The battery box must be coated with a non-conductive, electrolyte-resistant coating.

7. The battery box should contain absorbent material in case there is a leakage of electrolyte.

8. If venting to the cargo bay, the battery box must be air-tight and the integrity of the seal must be verified. The purpose of venting is to prevent the accumulation of combustible gases.

9. If venting to the inside of the GAS canister, a free volume analysis must be performed which shows that under worst case conditions, a combustible atmosphere in the free volume of the canister is not possible. The experimenter is required to provide data in support of the free volume analysis.

Figure 6 is a sample Hazard Report detailing the hazards and controls associated with the battery system. It should be used as a guide in the preparation of the experiment's unique Hazard Report. It is also a good start for the preparation of the safety assessment. Finally, the following documents should be referenced when designing the battery system:

1. NSTS 1700.7B - Safety Policy and Requirements
2. NSTS 18798A - Interpretations of NSTS Payload Safety Requirements
3. JSC 20793 - Manned Space Vehicle Battery Safety Handbook
4. Get Away Special (GAS) Experimenter Handbook (1991)

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PAYLOAD HAZARD REPORT	No.

PAYLOAD	PHASE

SUBSYSTEM Electrical	HAZARD GROUP Explosion/Corrosion	DATE

HAZARD TITLE
Rupture of XXXX battery cells

APPLICABLE SAFETY REQUIREMENTS NSTS 1700.7B: 206 Failure Propagation 219 Flammable Atmospheres 208.5 Sealed Compartments 213 Electrical Systems 209 Materials	HAZARD CATEGORY	
	X	Catastrophic
		Critical

DESCRIPTION OF HAZARD
Rupture of XXXX battery cells and the release of battery electrolyte.

HAZARD CAUSES
1. Battery overcurrent/short circuit.
2. Evolution of hydrogen and oxygen in the presence of an ignition source.
3. Electrolyte leakage.
4. Cell reversal.

HAZARD CONTROLS
1. (a) Negative ground leg of each string is fused (as appropriate to wire size) within battery box in
      accordance with NSTS 18798A, ER-87-326 and fuse is sized to protect battery from overcurrent condition.
  (b) Battery box internal coating (Conathane EN-11) is non-conductive.
2. (a) Sealed battery box (proof pressure tested to 22.5 psi)/Redundantly vented overboard using 15.0 psid valves
  (b) Battery box purged with nitrogen.
  (c) Contained in a sealed GAS canister that is purged with nitrogen.
  (d) Potential ignition sources conformally coated and fuses sealed.
3. (a) Battery box internal coating (Conathane EN-11) is inert to sulfuric acid electrolyte.
  (b) Use of absorbent material in battery box.
4. Parallel cell strings are diode isolated.

SAFETY VERIFICATION METHODS
1. (a) Design review (see attached electrical schematic).
  (b) Design review; Materials review.
2. (a) Proof pressure test of battery box/Standard PRV refurbishment checkout.
  (b) Battery box purged with nitrogen by GAS Field Operations personnel.
  (c) GAS Can purged with nitrogen by GAS Field Operations personnel. Standard Sealed GAS Canister
      Assembly/Integration Procedure.
  (d) Design review.
3. (a) Design review.
  (b) Design review.
4. Design review (see attached electrical schematic).

STATUS OF VERIFICATION
1. (a) Closed. GSFC Design Review (XX/XX/92).
  (b) Closed. GSFC Design Review (XX/XX/92) and GSFC Materials Approval (XX/XX/92).
2. (a) Closed. Test Report #xx (XX/XX/92)/To be performed at KSC (Procedure number GA37-300-11) and
      documented in the VTL.
  (b) Closed. To be performed at KSC (Procedure number GAS CAN-08-011) and documented in the VTL.
  (c) Closed. To be performed at KSC (Procedure number GAS CAN-08-011) and documented in the VTL.
  (d) Closed. GSFC Design Review (XX/XX/92).
3. (a) Closed. GSFC Design Review (XX/XX/92).
  (b) Closed. GSFC Design Review (XX/XX/92).
4. Closed. GSFC Design Review (XX/XX/92).

PHASE III APPROVALS	GAS P/L Manager	GAS Safety Officer
	GAS Project Manager	STS

JSC Form 542B (Rev Nov 82)   NASA-JSC

FIGURE 6 - SAMPLE ELECTRICAL HAZARD REPORT