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PRELIMINARY EVALUATION OF
REGULATORY AND SAFETY ISSUES FOR SODIUM-SULFUR BATTERIES
IN ELECTRIC VEHICLE APPLICATIONS

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PRELIMINARY EVALUATION OF REGULATORY
AND
SAFETY ISSUES FOR SODIUM-SULFUR BATTERIES
IN ELECTRIC VEHICLE APPLICATIONS

1. INTRODUCTION

1.1 Background

The U. S. Department of Energy (DOE) Electric and Hybrid Vehicle Program is involved in the development and evaluation of sodium-sulfur energy storage batteries for electric vehicle (EV) applications. Laboratory testing of complete battery systems, to be followed by controlled in-vehicle testing and on-road usage, are expected to occur as components of the DOE program during the 1988-1990 time frame. As an example, the Ford ETX-II propulsion system development program will result in the delivery to DOE of a test bed vehicle incorporating a sodium-sulfur traction battery in FY-1989. This test bed vehicle and its accompanying battery system will be extensively tested at Ford and at the Idaho National Engineering Laboratory (INEL), and it may subsequently be operated in the field. Testing and operation of sodium-sulfur batteries at other DOE contractor facilities may also take place during this time frame.

A number of regulatory and safety issues can affect the technical scope, schedule, and cost of the expected programmatic activities. This document describes these issues and requirements, provides a preliminary evaluation of their significance, and lists those critical items that may result from them. The actions needed to permit the conduct of a successful program at DOE contractor facilities are identified, and concerns that could affect the eventual commercialization potential of sodium-sulfur batteries are noted to the extent they are known.

1.2 Subtasks and Agencies Involved

The planned program can be broken down into broad tasks that involve the transportation, operation, and disposal of sodium-sulfur batteries. Shipment of batteries, either from the supplier to a DOE contractor initially or from the contractor to a disposal facility at the end of the program, is regulated by the U. S. Department of Transportation (DOT). Operations at DOE contractor facilities are governed by the terms of their contracts with DOE. Operational safety at these facilities is typically a responsibility of line management. Certain vehicle safety and performance requirements may need to be met during testing or operation to comply with DOT and DOE regulations pertaining to electric vehicles. Disposal of spent batteries and any associated processing will be subject to regulations imposed by the U. S. Environmental Protection Agency (EPA). In certain cases local jurisdictions may also impose additional restrictions.

1.3 Structure of This Report

The following sections outline regulatory requirements and safety issues as they apply to shipping, operation, and disposal during the planned program. Regulatory or safety requirements that may comprise critical path items are highlighted. A general task breakdown is outlined, and a summary of critical path items for the program is

presented. Appendix A briefly describes the sodium-sulfur battery, Appendix B discusses general safety issues, and Appendices C, D, and E list and discuss the titles and parts of the Code of Federal Regulations (CFR) pertaining to hazardous material shipping, sodium-sulfur battery-powered EV operation, and hazardous material disposal respectively.

2. SHIPMENT OF SODIUM-SULFUR BATTERIES

Sodium-sulfur batteries can be shipped either hot or cold. Cold batteries can be shipped:

- 1) having previously been hot, or
- 2) having never been heated up.

Similarly, hot batteries can be shipped:

- 1) at the operating temperature of about 350°C, or
- 2) at a reduced temperature (e. g., 120°C, which is about the minimum temperature at which sodium and sulfur are liquid.)

2.1 Cold Shipment

Cold sodium-sulfur cells may be shipped in accordance with shipping regulations that pertain to sodium metal, if evidence has been provided to DOT that such shipment would create no greater hazard than that which exists in shipping sodium alone. Ford Aerospace and Communications Corp. (FACC) developed such evidence by carrying out numerous safety tests for their cells and batteries which simulated normal and adverse transportation conditions. These tests (vibration, dropping, exposure to open flame, temperature extremes, crushing and water immersion) identified no additional hazards. Based on these results, DOT's Office of Hazardous Materials Operations granted FACC approval to ship sodium-sulfur cells labeled as "SODIUM, METAL" in standard shipping containers authorized for sodium. It is therefore inferred that similar approval can be obtained for cells from other sources.

In the case of complete sodium-sulfur batteries, the FACC thermal enclosure did not meet the requirements for standard sodium shipping containers. FACC was required to obtain an exemption for the transportation of their sodium-sulfur battery at ambient temperature. The exception obtained from DOT stipulated that a "proper shipping name" was not required, but required that the sodium be contained in hermetically-sealed cylindrical cell casings, and that the cells be contained in a double-walled steel battery enclosure. Similar provisions can be expected for batteries obtained from other suppliers.

It is anticipated that cells and batteries for this program can be shipped cold under provisions similar to those outlined above. However, at the present time, shipping cold cells that have previously been operated hot is considered to present an unacceptable risk of freeze-thaw damage to the solid electrolyte. Such damage can be avoided by shipping cells cold, never having been hot. It is expected that future electrolyte development will permit cells to withstand repeated freeze-thaw cycles. For the time being, shipping cold cells that have never been hot appears to be the preferred choice, although some concern exists regarding activation of the cells away from the vendor's facilities.

2.2 Hot Shipment

In the event that shipment of cold cells that have never been hot is not practical, hot shipment may be required. Therefore it is prudent to plan for hot shipment, which has not yet been formally considered by DOT. Obtaining the necessary approvals to meet DOT requirements could constitute a critical path item for ETX-II testing. Accordingly, this issue should be addressed at the outset to avert delays later in the program.

Hot shipment offers the clear advantage that the battery can be tested and verified to be functional by the vendor before shipment, with the likelihood that it will function on delivery without additional vendor intervention because the battery has not been subject to a freeze-thaw cycle. If hot shipment is necessary, it will be preferable to ship hot at a temperature around 120°C rather than at 350°C, because this will provide a large safety margin for cell overtemperature. Cell temperatures beyond approximately 550°C are expected to cause leakage of cell contents, as discussed in Appendix B. In addition to the added thermal margin, shipment at a lower temperature will also increase electrolyte resistance and reduce the ability of a short circuit to heat the cells. Finally, lowered temperature may also reduce the rate of reaction between sodium and sulfur should electrolyte failure occur. Shipping hot at 120°C offers a significant degree of safety margin, which should aid in obtaining the necessary approvals from DOT.

Since the need for hot shipment cannot be ruled out, addressing DOT requirements for hot shipment (see Appendix C) is recommended even though cold shipment is preferred as the simpler short-term approach.

3. OPERATION OF SODIUM-SULFUR BATTERIES

In the area of operational testing, safety concerns have been a major focus throughout the development of sodium-sulfur batteries. Cells are designed with strong cases to confine the overpressure that would result from accidents such as a broken electrolyte or a short circuit. Also, the quantity and mobility of sodium are kept as low as possible, to minimize the extent of reaction resulting from electrolyte failure. Seal failure with consequent cell leakage can occur with overtemperature, which is considered the worst accident that is credible for an individual cell. Batteries are designed so that complete failure of a single cell will not propagate to adjacent cells. Nevertheless, carefully-designed sodium-sulfur battery crash tests will probably be needed prior to commercial sales of EVs using such batteries. The results of the proprietary Brown, Boveri & Cie crash tests, if they can be made available, should be useful in persuading DOT of the safety and crashworthiness of sodium-sulfur batteries in electric vehicles.

DOT approval to operate DOE test vehicles on public roads during the proposed test program can probably be obtained with less effort than EV vendors will need to expend before sales to the general public are made. However, discussions with DOT should be initiated early so as to clearly define their information needs. The experience of FACC in obtaining an exemption for the shipment of sodium-sulfur batteries for testing may be viewed as a precedent for DOT's willingness to provide exemptions for limited and controlled test and evaluation programs.

Beyond DOT regulations, some local jurisdictions restrict access to tunnels, bridges or other areas on the basis of a variety of safety concerns. State and local restrictions have been important in shipping liquid natural gas and spent nuclear reactor fuel, for example. It will be necessary to initiate discussions with affected local governments relative to shipping and on-road testing. The possibility does exist for the eventual commercial use of sodium-sulfur batteries to be limited by local restrictions, but timely and appropriate regulatory action by DOT should minimize the impact of such concerns.

4. DISPOSAL OF SODIUM-SULFUR BATTERIES

4.1 Disposal by the Battery Vendor

An option that could circumvent any involvement by DOE or its contractors in disposal issues would be to lease the batteries from the manufacturer or vendor, who would then be responsible for their eventual disposal. A variant of this option would be to purchase the batteries under a contract which requires the vendor to accept them back for disposal at the end of the program. Such an option is clearly preferred for the planned test program unless considerations other than disposal mitigate against it. However, it requires a willing vendor, so discussions with potential vendors should be initiated early so that enough information is available for a timely informed decision.

It should be noted that Ford is already engaged in such discussions with vendors regarding the lease or purchase of the sodium-sulfur battery to be provided with the ETX-II test bed vehicle. The technical responsibility for this decision rests with Ford. However, the consequences of this choice will subsequently devolve upon DOE or INEL for operation and disposal of the battery. Discussions with Ford regarding the issues raised in this report may therefore be appropriate.

4.2 Disposal by the User

Battery leasing or otherwise holding the manufacturer (and not the user) responsible for disposal may not be practical for either initial testing or eventual widespread application of sodium-sulfur batteries. Consequently some consideration will be given to regulatory disposal concerns.

Recycling spent sodium-sulfur batteries through local commercial channels would be preferable to disposal as a waste, and this method of disposal can be expected to become available if enough commercial vehicles are produced. However, no such outlet is expected to be available during the test program. Hence the expected disposition of spent batteries from the proposed test program would be burial in a landfill. DOE laboratories such as INEL typically have no approved landfill, so disposal at an approved commercial facility must be considered.

As noted in Appendix E, EPA prohibits disposal of freestanding liquids and reactive or toxic materials in a landfill, so no commercial operator can accept the spent sodium-sulfur batteries unless metallic sodium is first removed. Three possibilities for disposing of metallic sodium exist:

- 1) complete discharge of the cells, which theoretically converts the sodium to sodium sulfide,
- 2) recycling by commercial sodium recycling channels, or
- 3) chemical inactivation by conversion to sodium oxide, followed by neutralization with acid to form nonhazardous sodium chloride or sodium sulfate.

These options are listed in decreasing order of desirability. However, it is uncertain whether all of the sodium will truly be consumed by complete discharge. The authors of this report know of no commercial sodium recycling channels, but this does not rule out their existence. (It should be noted that recycling is a distinct possibility if the number of spent batteries becomes large, since the production of sodium is an energy-intensive process.) The need to process the sodium to a nonhazardous form could add significantly to the cost of the program, since a processing facility may have to be built, and the processing of hazardous materials requires permission from EPA.

Since leachable toxic materials cannot be buried, disposal of spent batteries (with sodium removed) in a landfill will also require demonstration that the amount of sodium sulfide leached from spent cells will be within prescribed limits. Spent cells from which the sodium has been removed may meet this requirement due to the sealed cell containers. If sodium sulfide proves to be leachable from spent cells, however, it must be either (1) removed, possibly by shredding and leaching, or (2) immobilized, perhaps by encapsulation in concrete. If the sodium sulfide is removed by leaching, the aqueous solution thus generated can be rendered nonhazardous by addition of ferrous sulfate, which would yield insoluble ferrous sulfide and sodium sulfate, both of which are nonhazardous.

Any processing facilities associated with treating spent cells so that they can be buried must obtain a permit from the EPA, which can be a long, costly process. Thus, the disposal needs must be clarified, and discussions with appropriate EPA officials initiated, early in the test program.

Shipping the spent cells to a commercial landfill for burial will possibly be covered by an extension to the provisions for shipping cold cells discussed in Appendix C. However, the labeling of "SODIUM, METAL" would no longer be required. Existing DOT regulations for solid sulfur and sodium sulfide may very well cover the mixed sulfur and sodium sulfide that would remain in spent cells from which sodium has been removed. Based on the reasoning applied to the shipping of cold cells, in which the labeling was based on the more-hazardous material (sodium), DOT might base the labeling on sodium sulfide rather than sodium metal, in which case larger amounts could be shipped in a single container and the packaging requirements would be less stringent.

5. TASK OUTLINE FOR SODIUM-SULFUR BATTERY TESTING

Tasks necessary for completing expected test activities for evaluating sodium-sulfur batteries are listed or outlined below in approximate chronological order.

Task 1. Literature Search for Pertinent Information

This activity, which will be directed toward obtaining the published information pertinent to resolution of safety and regulatory issues, is a continuation of the work performed to date to support the preparation of this document.

Task 2. Preliminary Discussions with Battery Vendors

This task will address primarily the lease/purchase and related disposal issues. Satisfactory resolution of these issues could result in minimizing the need for EPA involvement in DOE-sponsored testing and evaluation activities.

Task 3. Preliminary Discussions with Regulatory Officials

This will be a broad-based task which involves responsible officials in DOT, EPA, and DOE, initiating discussions directed toward defining the additional information required for issuance of permits or for rulemaking by these bodies, documenting the needs, and gathering the needed information. Obtaining each approval in time to proceed with the affected program activity has the potential to be the critical path for each such activity. Some ratcheting of requirements by the regulators is possible, but the impact of this can be minimized by obtaining a clear understanding of what is needed early in the program.

Task 4. Preliminary Discussions with Contractor Safety Group

Safety is typically the responsibility of line management at DOE contractor facilities, including the national laboratories. However, there is generally an internal safety group which can serve as a resource to assure that DOE contractual requirements relative to operational safety are met during the test program. Early discussions with such groups at the facilities where testing is expected to take place will help to prevent unexpected obstacles from developing.

Task 5. Supporting Experimental and Analytical Studies

This task will encompass bench-scale experimentation, data evaluation, calculational studies, and crash testing as needed to resolve safety and regulatory questions. It should build upon the results of previous and ongoing activities by battery vendors, DOE laboratories (e. g., Sandia) and other contractors (e. g., Ford).

Task 6. Procure Sodium-Sulfur Batteries and/or Vehicles for Testing

Procurement or leasing of sodium-sulfur batteries is expected to be a long lead-time activity, so this task will necessarily be initiated early in the program. Shipping requirements and procedures may have to be finalized later (i. e., after manufacture begins) due to the fact that definition of DOT requirements will evolve in parallel with procurement.

Task 7. Presentation of Supporting Evidence to Regulatory Officials

Since there are several federal agencies involved, this task will have several phases that may extend over a significant time period. Planning this task will need to allow for uncertainties in the time taken by the regulatory bodies to define applicable requirements for shipping, operating, and disposing of the batteries.

Task 8. Rulemaking by Regulatory Officials

The form which this task will take cannot be accurately predicted at this time. In the most favorable circumstances, the testing organization would receive letters granting approval with little fanfare. A more likely outcome is publication of proposed actions in the Federal Register, followed by a public comment period. The worst case scenario would be public hearings, with testimony from interested parties, possibly followed by additional information needs to be satisfied. Scheduling this task will be critically dependent on the results of Tasks 2 and 3 in order to take these uncertainties into consideration.

Task 9. Ship Sodium-Sulfur Batteries and/or Vehicles for Testing

This task cannot be initiated until approval to ship by DOT is granted. Approval to dispose of the spent cells may not be complete at this time, but it would be prudent (and may be required) for all disposal issues to be resolved prior to shipment.

Task 10. Laboratory and On-Site Testing.

Task 11. On-Road Testing.

Task 12. Disposal of Batteries.

6. SUMMARY OF CRITICAL ITEMS

A definitive listing of critical path items is not possible, due to the fact that several options have been identified, and the associated costs and schedules for these options cannot be accurately determined at this time. The major options involving potentially critical items are:

- 1) Hot vs. cold battery shipment, and
- 2) Leasing vs. purchase of batteries (which probably translates to vendor vs. user disposal of batteries).

6.1 Hot vs. Cold Shipment Option

The decision concerning hot vs. cold shipment involves the following trade-offs and other factors:

Shipping cold cells that have never been hot offers minimal risk that the cells will arrive damaged, but requires activation of the cells away from the vendor's facilities. If some cells are subsequently found to be failed on heatup, they must be replaced in the field, preferably with the battery hot.

Shipping cold cells that have previously been hot offers certainty that the cells are functioning properly before shipment, but has the disadvantage that the cells may suffer electrolyte damage due to freeze-thaw thermal expansion effects.

Shipping cold cells in either case has already been determined to be possible within DOT requirements, as discussed in Appendix C.

Shipping hot cells at 120 °C improves confidence that cells will arrive undamaged, but will probably require meeting additional DOT requirements. The need for activation of the cells away from the vendor's facilities can likely be avoided by testing the battery at operating temperature before shipment and then cooling it to the reduced temperature for shipment.

Shipping hot cells at 350 °C offers high confidence that cells will arrive active and undamaged, but will likely require meeting the most stringent DOT requirements.

6.2 Lease vs. Purchase Option

Assuming that battery vendors are amenable to leasing, the decision to lease or purchase the batteries is likely to be primarily a cost trade-off between added vendor costs (the vendor presumably will try to recover the costs associated with receiving the spent cells) and the added programmatic costs to define disposal needs and meet EPA requirements.

6.3 Possible Critical Items

Those items which may involve critical path activities, including those connected with the above alternatives, are listed below:

Discussions with DOT's Office of Hazardous Materials Operation to assess the probable impact of hot shipment.

Discussions with possible battery vendors relative to hot vs. cold shipping trade-offs, whether the leasing option will be available, and who will pay customs duties or bonds in the event that the vendor is not located in the United States.

Discussions with DOT relative to how (or whether) vehicle safety standards will be applied to test vehicles and to subsequent field use vehicles.

Discussions with affected local jurisdictions relative to battery and spent cell shipment as well as vehicle testing.

Discussions with EPA (if required) concerning disposal and transportation requirements for shallow land burial and obtaining a permit to process sodium at an appropriate facility.

Discussions with local (i.e., contractor) safety groups to clarify the program's obligations concerning operational safety.

Appendix A
Description of the Sodium-Sulfur Battery

APPENDIX A

DESCRIPTION OF THE SODIUM-SULFUR BATTERY

The sodium-sulfur battery is based on the reaction between sodium and sulfur, as described below.

The sodium and the sulfur are liquid at the usual operating temperature of 350°C and are separated by a solid sodium oxide/aluminum oxide electrolyte. A typical type of cell design uses a cylindrical sodium anode surrounded by the annular electrolyte, which is in turn surrounded by the sulfur cathode. The outer canister is variously aluminum or chromium-plated ferritic stainless steel. As the cell discharges, the forward reaction takes place, forming sodium ions at the anode and sulfide and polysulfide ions at the cathode. The sodium ions diffuse from the sodium region through the electrolyte to form sodium sulfide and sodium polysulfide in the sulfur region. Recharging the cell reverses the direction of the reaction and converts sodium sulfide and sodium polysulfide to sulfur and sodium.

Appendix B
General Operational Safety Issues

APPENDIX B

GENERAL OPERATIONAL SAFETY ISSUES

During the development of the sodium-sulfur battery, there has been an appreciation of the degree of accident hazard potential. Since accident hazards are considered to be most severe during cell operation, this discussion deals with hazards associated with active cells at normal operating temperature (350°C).

For the purposes of this discussion, accidents are assumed to result from either a system failure or a vehicle collision. System failures are defined as cell failures not resulting from outside forces. Vehicle collisions will subject the cells to acceleration forces they are not designed to withstand. It is presumed that cell failure due to accidents cannot be entirely prevented. Accordingly, measures that reduce the likelihood of and minimize the consequences of cell failure are discussed below.

Cells are designed for minimal leakage of cell contents due to uncontrolled reaction between sodium and sulfur in the cell. This criterion is the key to achieving the more important design requirement that damage must not propagate to adjoining cells. Thus, the cells in a battery must be arranged in such a manner as to minimize cell damage propagation.

Factors that can lead to cell leakage are electrolyte breaching, cell canister rupture, and seal failure.

A major cause of electrolyte breaching is overcharging, which can be controlled (but not eliminated, because of potential imbalances among cells) by a charger of fail-safe design. Studies and operating experience indicate that cell leakage caused by electrolyte breaching is a low-probability event except for those induced by freeze-thaw cycles.

Failure of the cell canister, which is the cell pressure containment, would obviously produce cell leakage. Such a failure could be caused by sodium sulfide^a corrosion. The canister can be designed to be strong enough to minimize such failures.

-
- a. Liquid sulfur is a mixture of sulfur with a number of sulfur polymers. Such a mixture is often referred to as polysulfur, and the reaction product of polysulfur with sodium is sodium polysulfide. For convenience, we refer to the sodium sulfide/sodium polysulfide mixture as sodium sulfide.

Failure of the seal will also produce cell leakage, and the available information indicates present seals have an upper temperature limit of about 550°C. A short circuit of the cell can cause such an overtemperature condition. It may be possible to design cells such that seal failure does not occur as a result of short circuits, but existing cells are not assured to maintain integrity under overtemperature conditions.

Thus, cell leakage cannot be ruled out, although proper design can minimize the likelihood of catastrophic results.

Release of hot sulfur and sodium onto the test stand or into the EV's battery case presents a significant hazard, due to formation of sulfur dioxide and sodium oxide, respectively. Also, hot sulfur and sodium in contact with each other react rapidly and exothermically, producing sodium sulfide. Finally, should hot sodium come in contact with water, hydrogen is evolved so rapidly that an explosive mixture with air can form and, at the temperature involved, it will likely detonate. The chemical hazards associated with sulfur dioxide, sodium oxide, and sodium sulfide are listed in Table B1 and are discussed further below.

The sodium-water reaction presents the most significant hazard associated with sodium-sulfur battery usage. Normal safety precautions will prevent occurrence during laboratory testing, but such an event cannot be ruled out during shipping and EV operation. Since many cities are located on a river or near a body of water, an accident that releases sodium, followed by water immersion, cannot be ruled out. Such an accident could result from a collision severe enough to both cause cell leakage and rupture the battery chamber, with the EV continuing on into the water. The cell casing is designed to be strong for reasons given above, and the battery chamber will need to be strong to meet DOT requirements, as outlined in Appendix C. Due to the extensive chain of events required for sodium-water reaction to occur, the occurrence of a sodium-water reaction during controlled testing is considered to be highly unlikely.

Significantly more likely is a collision that would cause cell leakage into a ruptured battery chamber, but without immersion in water. In this case, sulfur dioxide production is the principal hazard. A fire in the battery case might be self-limiting, since the thermal expansion of the gases in the battery case would tend to exclude fresh air from the battery case while consuming the available oxygen, thus limiting the amount of sulfur dioxide that could be formed. The formation of sulfur dioxide would be further limited by sodium competing for the available oxygen. (Sodium oxide, a solid, would be substantially confined to the battery case.) With a hermetically sealed battery case, a considerable enhancement of safety would be provided by a nitrogen atmosphere inside the case. To aid in clarifying the various design trade-offs, it is recommended that a probabilistic risk analysis be performed. This analysis will allow estimating the likelihood of occurrence and consequences of the hazardous events that can possibly occur.

Useful perspective on sodium-sulfur battery hazards can be seen by considering the likely result of a probabilistic risk analysis applied to gasoline-powered automobiles. Both fire and explosion potential are always present with operating gasoline engines, yet automobiles are considered to provide an acceptable risk/benefit ratio. It should be possible to demonstrate that sodium-sulfur batteries also provide an acceptable risk/benefit ratio. For example, a simplistic calculation indicates that the

energy released by completely reacting the sodium in a 40 kW sodium-sulfur battery with water (a highly improbable event) is approximately equal to that produced by burning 2 gallons of gasoline. However, other considerations such as the production of hydrogen by the sodium-water reaction suggest that more detailed risk assessment analyses will ultimately be required.

Chromium compounds result from corrosion of the chromium in the stainless steel cathodes. Since they are trivalent compounds, they are classified by EPA as less of a concern than hexavalent chromium. Furthermore, quantities are so small as to contribute little hazard potential over and above the other hazards.

Table B-1

Hazardous Chemical Species Associated with a Sodium-Sulfur Battery

<u>SPECIES</u>	<u>SAFETY CONCERN</u>
Liquid sodium	Hot, toxic (a), reactive, burns in air, reacts violently with liquid sulfur, reacts explosively with water.
Liquid sulfur (b)	Hot, burns in air, reacts violently with liquid sodium, contaminated with sodium sulfide and sodium polysulfide.
Sodium sulfide (b)	Toxic, can explode on percussion or rapid heating.
Sodium oxide	Toxic, damages human skin and mucous membranes.
Sodium hydroxide	Toxic, damages human skin and mucous membranes.
Sulfur dioxide	Toxic, heavier than air.
Chromic sulfide (c)	Toxic, not appreciably soluble in water, reacts explosively with chromium trioxide.
Chromium trioxide (c)	Toxic, comparatively soluble in water, reacts explosively with chromic sulfide.

- (a) The term "toxic" indicates a toxicity rating of 3 as defined in Sax. (N. I. Sax, Dangerous Properties of Industrial Materials, 6th Edition, Van Nostrand Reinhold, 1984)
- (b) The sulfur phase contains various sulfur polymers, usually designated as polysulfur. Polysulfur reacts with sodium to form sodium polysulfide.
- (c) Chromium ion may be formed in the sulfur phase from corrosion of chromium.

Appendix C

DOT Requirements for Shipment of Sodium-Sulfur Cells

APPENDIX C

DOT REQUIREMENTS FOR SHIPMENT OF SODIUM-SULFUR CELLS

The US Department of Transportation (DOT) regulates shipment of hazardous substances. Title 49 of the Code of Federal Regulations, Parts 171-179, contains the regulations pertinent to hazardous material shipping. Both the State of Idaho and the City of Idaho Falls currently accept DOT primacy in this area.

The applicable regulations governing the shipment of sodium-sulfur cells (labelled as "SODIUM, METAL") are described in Title 49 of the Code of Federal Regulations, Part 172.101 (designated as 49 CFR 172.101) when packaged according to the requirements of 49 CFR 173.206(a)(4) or (a)(5). The requirements of 49 CFR 172.101 related to shipping sodium are summarized as follows. The proper shipping name is "SODIUM, METAL" or "SODIUM, METALLIC." Labels indicating "FLAMMABLE SOLID" and "DANGEROUS WHEN WET" are required. Transportation of sodium is forbidden on passenger-carrying aircraft or ships. On cargo-only ships, the maximum quantity per package is 25 lb. In all cases, sodium must be packaged according to 49 CFR 173.206. Parts of this paragraph apply only to other flammable solids, and some do not allow drums with removable heads: hence, only parts (a)(4) and (a)(5) were selected as applicable to the shipment of Ford Aerospace sodium-sulfur cells.

Packaging under 49 CFR 173.206(a)(4) is based on the use of Specification 37A or 37B single-trip metal drums not exceeding six gallons each, and packaged with not more than four drums in a strong outside wooden box per requirements further defined by 49 CFR Part 173.25. The drums must have "welded side seams and a hermetically sealed closure or a closure made fast by positive pressure of the lid against a rubber gasket with the edge of the lid crimped over the lip of the drum and a protective metal ring fastened around the crimped edge." The drums must be cushioned on all sides with incombustible packing material. Required characteristics of Specification 37A and 37B drums are provided in 49 CFR 179.131 and 49 CFR 178.132, respectively. A major difference between the two is that for Specification 37B drums, removable heads are not authorized, making their use for cell shipment impractical.

Packaging under 49 CFR 173.206(a)(5) is more applicable for shipment of sodium-sulfur cells and modules. This part of the paragraph is based on the use of Specification 17C metal drums which are defined by 49 CFR 178.115. This specification covers removable-head drums of several sizes up to and including 55 gallons. These drums must be made of heavier gauge steel (16-gauge for the 55-gallon size) than Specification 37A drums, and therefore do not require additional outside packaging. It should also be noted that 49 CFR 173.28(m) allows the reuse of Specification 17C drums for flammable solids, providing the drums are cleaned, inspected for defects, and tested by a registered drum reconditioner. The cover gasket must be replaced prior to reuse.

The regulations described above are applicable to cold shipment of sodium-sulfur batteries. Hot shipment requires consideration of additional hazards associated with liquid sodium, for which no information is given in 49 CFR Part 172.101. However, a reasonable analogy for liquid sodium may be liquid sodium-potassium alloy, which, according to Part 172.101, can be shipped under the rules that apply to sodium metal, with the following modifications:

The maximum amount per package is one pound, instead of 25 pounds.
The packaging requirements are defined in Part 173.202, instead of Part 173.206.

Underdeck stowage must be readily accessible.
Package labelling would be "SODIUM, METAL", and "HAZARDOUS SOLID", and "DANGEROUS WHEN WET", as in the case of solid sodium.

Regulations pertaining to sodium sulfide can be found in 49 CFR Part 172.101, and to molten sulfur in Part 172.102. Both materials are to be labelled "FLAMMABLE SOLID". In the case of sodium sulfide, packaging is defined in Part 173.207, up to 100 pounds can be contained in a package, and stowage must be separated from liquid acids. Molten sulfur must be labelled "FLAMMABLE SOLID", no limit on quantity per package is prescribed, and stowage must be away from oxidizers and living quarters.

If these regulations are taken separately, no conflict in regulations for sodium, sulfur, and sodium sulfide is evident. Clearly, however, the regulations governing sodium are the most restrictive and are therefore controlling. The regulations are essentially silent regarding the manner in which molten sulfur and sodium should be shipped in the same container, though useful perspective can be obtained by noting that regulations for shipping a variety of explosives are provided. By inference, with proper concern for packaging, stowage, labelling, etc., it should be possible to ship hot sodium-sulfur batteries. It is noted that a report in the National Fire Protection Association (NFPA) guide indicates that sodium and sulfur can detonate when combined under certain conditions. However, verbal discussion with an NFPA representative suggests that the testing on which this indication is based may not be applicable to sodium-sulfur batteries.

The key issue in shipping hot sodium-sulfur batteries would appear to be the effectiveness of the alumina electrolyte as a barrier between sodium and sulfur. Conclusive resolution of this issue can come only from subjecting batteries to a wide range of controlled crash tests. In the final analysis, DOT will write the regulations governing shipment of hot sodium-sulfur batteries. Therefore, discussions will need to be initiated to identify the information needed for DOT to define the appropriate requirements.

If the battery is obtained from outside the United States, additional documentation may be required, due at least to the need to pass through U. S. Customs, which is part of the Department of Commerce.

Appendix D

DOT and DOE Rules Regulating Operation of Electric Vehicles

APPENDIX D

DOT AND DOE RULES REGULATING OPERATION OF SODIUM-SULFUR BATTERY-POWERED VEHICLES

The DOT regulations published in 49 CFR Part 571 define standards for vehicle safety, and deal with such issues as crashworthiness, damageability, crash avoidance, and hazards. As the term "passenger automobile" is defined by DOT, electric vehicles do not appear to be covered under this part. However, Department of Energy (DOE) regulations contained in 10 CFR Parts 475 and 476 prescribe that electric vehicles meet the DOT regulations, unless an exemption is obtained from DOT. DOE also prescribes additional requirements, most of which relate to range, acceleration, maximum speed, gradeability, instrumentation, etc. There may be a need to devote attention to assuring that the requirements are met by the test vehicle manufacturer, or to obtaining the necessary waivers from DOT. This is likely to be the case for commercial applications of electric vehicles, whatever their power source may be.

Demonstrated compliance with these requirements has not been a prerequisite to previous electric vehicle testing by DOE contractors, either in the laboratory or on the road. This is particularly true for R&D test bed vehicles, where the issue has been largely ignored in the past because of the experimental nature of the vehicles. However, discussions with the various regulatory agencies could possibly result in a change in this situation.

Appendix E

EPA Requirements Governing Sodium-Sulfur Battery Disposal

APPENDIX E

EPA REQUIREMENTS GOVERNING SPENT SODIUM-SULFUR BATTERY DISPOSAL

Of the planned activities in the proposed test program, disposal and shipment of spent batteries would be subject to environmental regulation. At INEL, for example, the US Environmental Protection Agency (EPA), the Idaho Department of Health and Welfare, and the city of Idaho Falls are responsible for environmental protection within their various jurisdictions. In Idaho, Region X of the EPA is responsible for regulating activities such as those contained in the proposed program. Since spent batteries would be considered to be a hazardous solid waste, and since the state of Idaho and the city of Idaho Falls currently recognize the primacy of EPA regulations in this area, applicable EPA regulations are expected to govern spent battery disposal. However, local jurisdictions can and often do impose more stringent requirements than EPA. For example, liquid wastes from the INEL Research Center (IRC) are subject to substantially more severe limits on pH than EPA prescribes.

The enabling federal legislation covering solid waste disposal is the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 (RCRA) and subsequent amendments. The language contained in 40 CFR Parts 240-271 outlines various standards and guidelines for generation, storage, transportation, and disposal of hazardous solid waste. In particular, Part 260 defines and classifies solid wastes, Part 261 identifies and lists hazardous wastes, Part 263 presents standards for hazardous waste transporters, and Part 270 outlines requirements for obtaining a RCRA permit.

Shallow land burial in a landfill is the most common approved method for disposing of solid waste such as spent sodium-sulfur batteries. Sodium and sodium sulfide are classified as reactive materials under Part 261.23, and sodium sulfide may possibly be classified as EP toxic¹ under Part 261.24, though this is unclear from the regulations. Disposal of reactive or EP toxic materials in landfills is prohibited.

According to Part 261.23, metallic sodium must certainly be removed from spent sodium-sulfur cells that are to be buried in a landfill. If commercial sodium recycling channels cannot be found, the sodium can be removed and converted first to sodium oxide, then neutralized with acid to form sodium chloride or sodium sulfate, either of which is considered nonhazardous and is easily disposable.

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- 1 The qualifier "EP" refers to "Extraction Procedure", so EP toxic involves a toxic material that is soluble enough to be leached from the solid waste under a standard test defined in Part 261, Appendix II.

Any facilities for treating spent cells prior to burial must meet the requirements of Part 270, which can be a long, costly process. Since commercial facilities cannot currently be expected to provide the necessary processing, it would probably have to be done at a government-owned facility such as INEL. Thus, the disposal needs should be clarified, and discussions with appropriate EPA officials initiated, early in the test program.

It will be necessary to perform EP toxicity testing, following the procedures of Part 261, Appendix II, to determine if the sodium sulfide is

leachable enough to classify the spent cells as EP toxic. If the cells are EP toxic, sodium sulfide must be removed from the cells or the cells must be encapsulated to prevent leaching. Similarly, it may be necessary to remove sodium sulfide due to its reactive classification, but this possibility should be evaluated further. Removed sodium sulfide can be treated by addition of ferrous sulfate to yield insoluble ferrous sulfide and sodium sulfate, both of which are nonhazardous.

Chromium corrosion products are potentially EP toxic, so it will be necessary to perform EP toxicity testing for chromium. It is probable that any necessary treatment of the spent cells because of sodium sulfide will also cover all any leachable chromium that may be present. Part 261.4(b)(6)(i)(A) appears to treat the trivalent chromium corrosion products in a less-restrictive fashion than would apply to hexavalent chromium.

- END -

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