Report of the Panel on Power Sources to the

Technical Coordination Committee

18 October 1972, Revision

This Report is believed to reflect Power Source efforts within this Agency. It understandably reflects the background and beliefs of the members of the Panel.

Respectfully submitted,

[redacted] 25X1

ORD/DD/S&T

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TSD/DD/P

[redacted] 25X1

OC/DD/S

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OEL/DD/S&T

[redacted]

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Report of the Panel on Power Sources to the Technical Coordination Committee

18 October 1972

(Written 5 May 1972)

(Revised 11 May 1972)

BACKGROUND

Overview

Power Source expenditures for R, D, T & E in the Federal Government has ranged from 148M in FY65 to 67M in FY71 (Table 1). This sum excludes prime movers (engines), spatial arrays, and nuclear reactor systems; it also excludes the major amounts of items buried within systems development programs such as the 120M plus for the Apollo fuel cell. It encompasses "packaged power" items of almost infinite variety. The current reference for Power Source activities is a series of Project Brief Sheets issued and maintained by the InterAgency Advanced Power Group. Some 2600 Briefs have been issued over the past 14 years!

The many energy sources and conversion systems provide a user with wide-ranging trade offs. Commercially, standardized sizes and capacities of many types exist to meet volume markets in a highly competitive cost situation.

Table 1

GOVERNMENT POWER SOURCE EXPENDITURES

Amounts in Thousands of Dollars

(Complied by Power Information Center)

	FY65	FY68	FY71	TOTAL 1965-1971
Electrochemical	$18,457	$11,299	$ 9,835	$ 84,080
Electromagnetic	1,835	1,604	261	7,280
Mechanical	86,627	39,136	30,016	323,064
MHD	3,047	3,409	2,225	19,248
Photoelectric	3,655	10,047	2,583	40,040
Power Conditioning	1,885	3,620	1,617	20,752
Solar - XX	1,715	875	1,673	7,222
Nuclear - XX	0	4,044	40	8,979
Thermoelectric	14,362	25,308	8,741	127,835
Thermionic	9,012	7,768	4,989	53,956
Miscellaneous	7,110	13,709	5,176	67,051
X-XX	0	0	66	106
TOTAL	$147,705	$120,819	$67,222	$759,613

Requirements for Agency use, however, invariably include operational features of life, duty cycle, form factor, etc., which lead to characterizing the bulk of our efforts as being in the Special Purpose Power Supply field.

Special Purpose Power Supplies cannot be developed without substantive interfacing with the using equipment. The power supply selected for applications engineering will range from an adaptation of established technology to the early exploitation of a new concept. In general such work is very costly, for user confidence can only be built upon test data derived from highly controlled, manufactured items. To develop, engineer, produce, and evaluate a new power source for operational use is typically a $500,000 effort over a period of several years. New efforts beyond the exploratory phase should not be initiated lightly. This state of affairs also points up the need for early coordination when new electronics systems are contemplated to reduce lead time and point up those new areas of power source technology which merit close attention to satisfy a need.

There is not, nor will there ever be, a universal power source. This being the case, this Agency, as well as DoD, AEC, NASA, and other governmental consumers, must remain knowledgeable with regard to all power sources and energy conversion capabilities and concepts. Selectively, power supply tasks are undertaken to satisfy customer objectives, and infrequently, research is undertaken on

identifiable, limiting materials or system problems. It is noted that the Power Source field is rarely given sufficient attention early in a systems program, perhaps because it is a field in which almost every engineer considers himself self-sufficient yet the many power sources problem areas contradicts this assumption.

Major Power Source Fields

To provide an added perspective to the scope of this subject, it is useful to present a summary taken from the Charter Document of the InterAgency Advanced Power Group (PIC 119/1.4, November 1963). The classification of the Technical Fields of Interest is:

Electrical - Energy conversion to electrical forms, including electrical energy control, by electromechanical, electromagnetic, electrostatic, magnetohydrodynamic, electronic, and solid state devices, excluding photovoltaic and photoemissive devices.

Electrochemical - All electrochemical systems, including chemical batteries, biochemical devices, simple fuel cell systems, and regenerative fuel cell systems, regardless of the source of energy for regeneration.

Mechanical - Energy conversion to mechanical, hydraulic, and pneumatic energy. Includes working fluids, materials, heat transfer processes, heat

transfer and storage equipment, and other components of mechanical conversion systems, including energy sources. Additionally, includes hydraulics, pneumatics, and lubrication developments.

Nuclear - Nuclear fission and radioisotope power sources and related systems.

Solar - Collection of solar radiation, its storage, and its conversion to heat or other energy forms. Includes photovoltaic and photoemissive devices and related systems.

It is the Brief Sheets issued by the Power Information Center (University of Pennsylvania) that provides the basic input to the establishment and conduct of any Special Purpose Power Supply program such as that required by the Agency.

Uniqueness of Agency's Requirements

The dominant influence on the Agency's requirements for power sources is the environment. Unlike the Military, NASA and the AEC, the overriding problems facing the power supply developer are concealment, detectability, very long service life, and highly unusual duty cycles to protect emplacements. Even the basic problem of reliability differs for one must prove long-term performance capabilities on nonproduction items and on an accelerated basis.

Any new need must start with an in-depth analysis of the using equipment and its operating environment. Will it be

employed on a mountain top, the desert, a city, or indoors or outside and in what climatic zone? As devices become more sophisticated and/or smaller and as operating environments become more hostile, new sources must be proven. Use is made of established National capabilities but a few illustrations will show wherein this organization is faced with R, D & E problems in order to exploit existing technology.

a. In the primary battery field, attempts are made to utilize known chemical systems, but no other consumer is faced with the problems of an [redacted] This Agency must therefore press for abnormally long-life performance and for high-energy density on a volume basis. 25X1

b. The secondary battery field has been highly developed by NASA. Since a majority of their cells are of the sealed type, they are not unique to space applications. Normally, this Agency needs only to select a battery type and interface it with the using system. Difficulties invariably arise however in gaining energy for recharging and in meeting weight and volume demands imposed by operational considerations. Difficulty also arises from the fact that despite NASA effort, there are only three battery systems available to choose from when designing a secondary battery power source.

c. The solar conversion field has seen NASA R&D expenditures estimated at well over one hundred million dollars. This Agency when faced with terrestrial needs

contends with a whole set of new parameters--weather, dirt, covertness, and variable light incidence spectrally, directionally, and in intensity--all of which requires deviations from NASA-optimized equipment for space.

d. Even in the nuclear power source area, the Agency's operating environments pose problems not faced by the AEC in their role as the prime movers in such developments.

[redacted] 25X1

1 [redacted] Further, the fact that our devices are oriented to foreign use introduces an entirely new consideration, i.e., the political. Normally, the application of a nuclear source can be stated; Agency use of a nuclear source requires even greater concern with concealment.

LONG RANGE OBJECTIVES

Technical

Long range objectives necessarily reflect recognition of the fact that most technical collection systems become power or energy limited as the result of size, weight, life, and related parametric requirements placed upon the power source. These limitations demand a very early consideration of power source capabilities in the development of any collection system. One cannot establish simple goals of energy or power density. One can identify significant functional areas for which a major advance is needed. These are identified below; comments

relative to their solution are presented in the material included in the discussion of the various energy conversion systems and projects.

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Organizational

This Panel believes that there is a need to consolidate and strengthen the Power Source Activities within this Agency,

if the highest level of capability is to be attained. The present diffuse staffing and programming is detailed under CURRENT CAPABILITIES. This objective is developed in some depth in a discussion associated with a RECOMMENDATION.

CURRENT CAPABILITIES

Technical

Propulsion Power. In the small engine field for platform propulsion needs this Agency has recently opened new capabilities with small Wankel Engines and an advanced 4-cycle engine in the few horsepower range. No further R&D is necessary at this time unless one was to undertake an isotopically heated Stirling engine; marine requirements might justify such an effort but it would be costly, long and complicated by political operational problems. Battery packs will continue to find use (especially for marine vehicles) in spite of severe limitations.

Auxillary Power. No particularly unique capability has been identified. Various mechanical systems (engines with motor generators) [redacted] 25X1

1 [redacted] are available for the Office of Communications. The special requirements of the Office of Special Projects are met by the massive programs of NASA and of the AEC.

Emplaced Systems. This requirement area is perhaps the most complex. Operational situations and energy demands are

so varied that almost all types of energy conversion systems have a role. At this time there is no significant inventory of capabilities from which to draw. [redacted] battery packs have been used, the latter also have used solar arrays to gain extended life. Each user need is the basis for a special study and trade-off analysis; an energy-limited compromise is usually necessary. 25X1

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Organizational

Technical Services Division. TSD has by far the strongest power source development program (excludes Office of Special Projects). It is highly purposeful and is making use of the

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Office of Research and Development. Appreciable talent exists but there is no strong on-going program primarily because of the lack of involvement in user requirements. R&D conducted in a vacuum in the power source field will rarely be productive. Advanced staff capabilities exist in small engines, special purpose batteries, nuclear systems, and environmental energy.

Office of Communications. Significant experience in evaluating and assigning power sources to a wide variety of equipments has produced a substantial know-how. Some exploratory assessments are made of new possibilities but with heavy emphasis on Test and Evaluation rather than R&D. The capability is largely in relating available hardware to very complex worldwide situations. Special capabilities are noted in electromechanical conversion systems ranging from diesel-electric to a variety of manually operated, mechanically driven generators. Experience exists with wind and solar conversion systems.

Office of Special Projects. This Office has highly specific needs which are generally satisfied by the R, D, T & E of the AEC for nuclear systems and of NASA for solar arrays and secondary battery storage systems. Details were not developed.

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ACTIVE PROGRAM INVENTORY

Power Source R, D & E Program

The organization of the programmatic content within this study is based upon functional requirements rather than energy conversion systems. This selection is made in spite of the overlap of given sources/systems with functions for it better reflects Agency interests. To present the material in a meaningful manner, a format has been established which is suited to the subject matter and which hopefully provides clarity in a concise form. It must be remembered that any given effort may well have fall-out values for functional uses other than that to which it is assigned. Table 2 summarizes resources. To provide perspective on the major energy conversion mechanisms, a brief summary by method is provided in Appendix A.

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EVALUATION OF PROGRAM ADEQUACY

Overview

The major technical efforts in the Agency are in TSD where a broad-based, objective effort is aggressively pursued and in ORD where a capability has been established [redacted] for use at audio levels. Other activities reflect either specific user system needs or scattered exploratory efforts. Exploratory efforts should be encouraged when related to the LONG RANGE OBJECTIVES (a) through (j) previously listed. Critical considerations are the technical concepts and the confining of efforts to prototypes until a specific application is defined as the basis for developmental specification. Continuing references to LONG RANGE OBJECTIVES have been presented within the detailed project section. Clearly, the present program is responsive to these Objectives.

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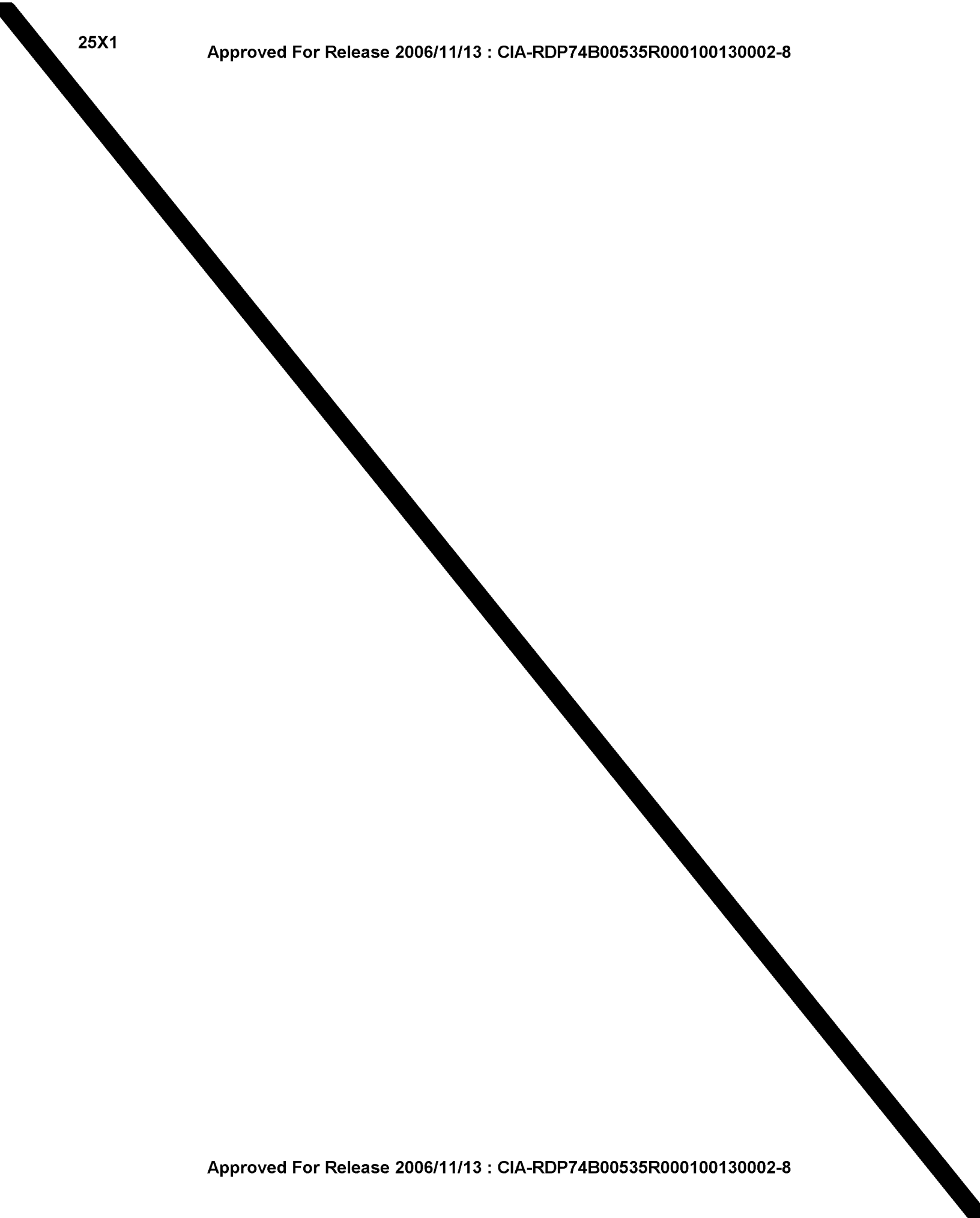
New Initiatives

The recommended expanded scope Power Source Program is given in Table 3. Projects reflect a priority ordering. This program does not include considerations of any desired increased level of effort of normal programming. Following Table 3 are specific discussions of each item presented.



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Terrestrial Solar Converters continue to receive wide consideration for this source and related converters offer the single best approach to using environmental energy. Limitations--diurnal, seasonal, meteorological and latitudinal--exist, therefore, a full system must encompass coupling and storage capabilities (see Hybrid Systems to follow). Isolated studies have been made by various Agency elements on array design, cell selection, operational conditions, camouflage, etc.

What is needed is a fully integrated program to establish expertise in the adaptation and exploitation of the massive space capability to the terrestrial environment. Energy levels, clandestinity, storage requirements are major points to be treated in establishing the in-house capability to evaluate effectively the capability of this approach to needs in the Auxillary Power, Emplaced Systems Power, and Audio Power areas.

Hybrid Systems as used here means power source capabilities involving low energy, long duration sources which are not suitable for direct use but ones which can be coupled to and used to maintain the charge on a secondary storage system. This secondary battery then actually powers the using equipment. Environmental energy (solar, wind, heat, etc.) depends on such storage to provide a continuous capability, and nuclear sources (high energy/low power) often use such storage to provide higher power capabilities.

There may be cases wherein a high capacity/low power electrochemical battery could be effectively used to maintain the charge on a small high-power battery. An example would be an improved solution to problems of Emplaced Systems wherein the energy requirement is for standby power, but the power requirement is set by transmitting power. These tend to be mutually exclusive in a single battery source.

The approach suggested would be an in-depth evaluation of storage (i.e., secondary) batteries with emphasis on those operational parameters of concern in Agency applications. Parameters of very low-level charging rates and of very long-term operation are outside of the considerations used by the developer in arriving at his product capability. Without a concerted Agency effort, this area will probably not develop systems useful to the Agency.

Micro Systems utilize power in a new and unique manner. Electronic functions and stages operate at the microwatt level. An orderly investigation should be undertaken of actual power needs by function or element and consideration should be given to supply these needs by highly stable sources matched to the need and supplied in component form for inclusion in the circuitry phase. With this approach, major gains should be possible in power economy (system life), in design simplification, and in system maintenance.

Fuel Cells, including metal/air types, should be reassessed for Auxillary Power and Emplaced Systems needs. The overriding capability, of course, is energy density; the level of prime value is for requirements of thousands of watt hours for extended times (years). The general deterioration of interests and capabilities Nationally have produced a very cloudy picture regarding Fuel Cell technology. A staff study is needed to put this field of endeavor in perspective and to determine what form of R&D should be undertaken. Interests tend to peak in terms of Blackbox requirements suitable to a hydrogen/oxygen form of cell and in the more difficult area of natural gas consuming fuel cell for worldwide Commo and Audio interests.

Technological Gaps

Gaps "for which no solution is currently foreseen" are rather hard to define for the limitation is generally one of

prohibition (policy or cost) or the lack of technical concept rather than one of theory. Nonetheless, the Panel has identified three points which merit consideration. These are Requirements, System Life, and a Data Base.

Requirements generally arise from a user's specification whereas they should be mutually developed with the power source expert. In this manner, trade offs can be made to the overall benefit of the system. Another aspect of the problem (which is probably not unique to power sources) is that very often the initiator of a requirement leading to an R&D effort is transferred overseas or to a new position and the R&D work accomplishment falls into a vacuum of "who wants this". This gap makes programming and accomplishment difficult and can probably be improved only by organizational changes.

System Life probably will remain the dominant problem until such capabilities as nuclear sources, solar arrays, and fuel cells are both available and operationally acceptable. Electrochemical systems have finite limits on energy and power density as well as stability. The concept of fully packaged energy for the multiyear duration of a system will probably be directly dependent upon an advanced nuclear capbility. (An exception in the sequential activation of reserve batteries is noted.)

Data Base problems always arise. The reason is simply that the Agency uses power sources in specialized ways which rarely parallel those of other consumers. Accordingly, manufacturers and developers have no incentive to acquire the data needed for our engineering evaluations of the usefulness of their products. Many examples can be cited wherein an outstanding power source has failed miserably because of a seemingly minor deviation in our use. The development of such a Data Base is very costly and of long duration. Work must be continued as at present (TSD and Commo); the compensating facet of broad expertise in power sources must be developed and used.

Parallel/Redundant Efforts

The nature of power sources is such that parallel approaches must be recognized and supported; such work is "not" redundant when the parallel efforts are evaluated in an environment free of the "nih" syndrome.

Lithium Cell Technology

From the list of individual projects presented above, it can be seen that there is a major effort (primarily in TSD) to exploit lithium anode electrochemical systems. These systems are all relatively new (two to three years at most) and much effort is needed to establish the real advantages of these systems. The term "lithium cell" is a misnomer in that there are more than a dozen present

systems which utilize lithium as the anode; each of these systems presents certain advantageous parameters. The R, D & E effort is in the process of evaluating these various systems to find the systems best suited to operational needs and to develop the advantageous parameters beyond present levels.

The similarity of projects in this area of the power sources effort arises from the fact that there is no extensive bank of experience on which to draw for information to allow a decision on which present systems should be pursued to the exclusion of others. Indeed, the field is expanding so rapidly that new systems are being developed by the industry monthly indicating that industry is not satisfied that present knowledge is sufficient for a focusing of product attention and effort. In order to monitor current industrial capability and progress, much effort is aimed at obtaining quantities of experimental or laboratory-produced cells for evaluation. Such evaluation requires hundreds of units for meaningful results and it provides the only bank of information for feedback to the producer relative to improvements on modifications necessary for certification for ultimate Agency deployment. In summary, there are many related or parallel efforts in the field of lithium anode electrochemical cells which appear to be redundant procurement actions, however, these

efforts are mandatory because of the infancy of this technology and because of the need to have experience and data upon which to base decisions on ultimate operational use.

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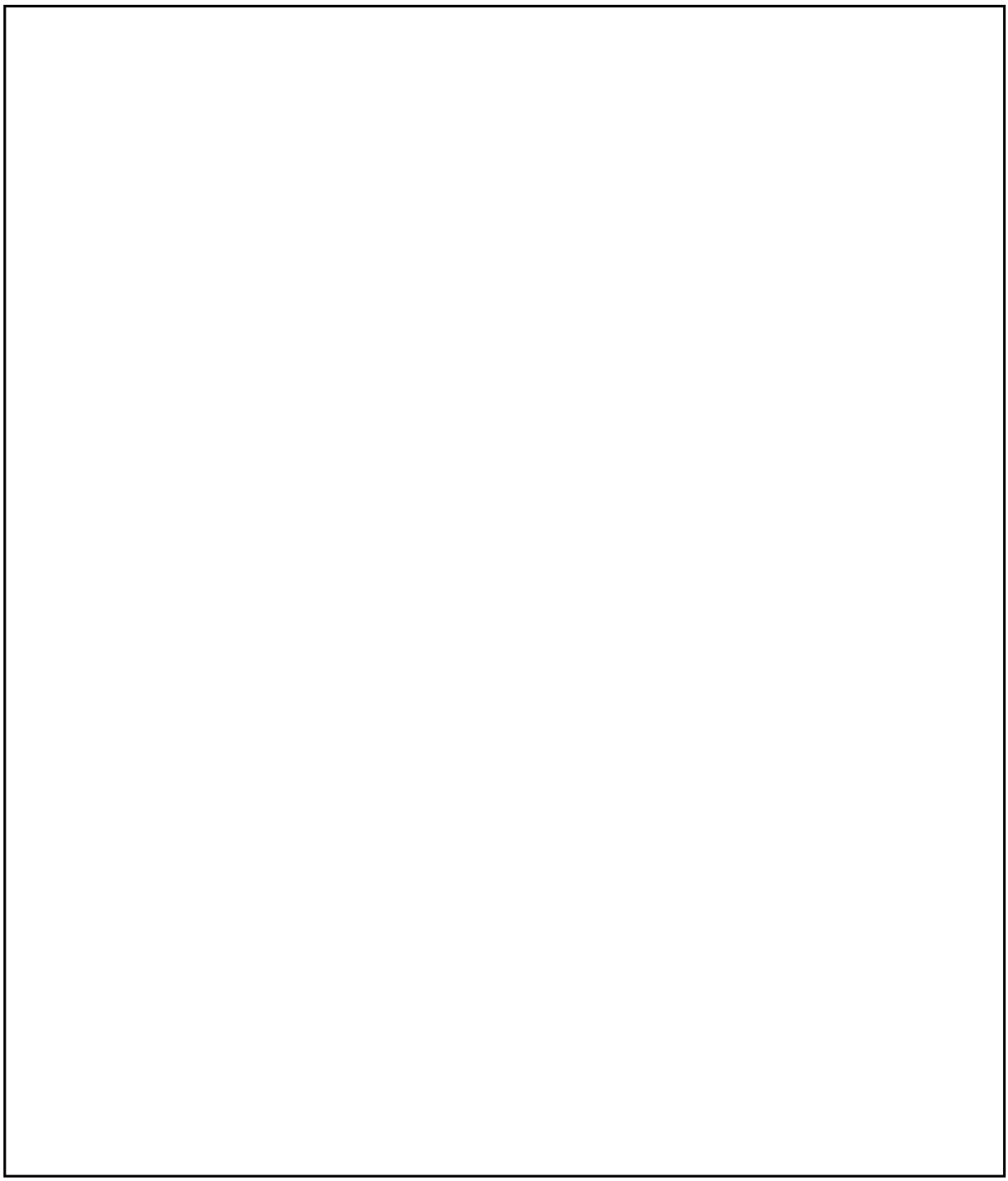

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Power Source Testing

Testing of power sources will probably have to be continued as separate Office responsibilities because of the diversity of requirements and because of the responsibility for the ultimate selection of a power source for a given equipment. This necessarily introduces parallel efforts with a somewhat inefficient use of resources. One method of overcoming this is described later in terms of a centralized Power Source Activity to encompass all Agency needs.

The testing of primary electrochemical cells (non-rechargeable) is inherently destructure and, hence, sufficient quantities must be tested to give an adequate statistical picture to the operational consumer. For this fundamental reason, testing of such power sources is and will be expensive. In addition, there is no known reliable method to accelerate the testing of batteries; and therefore, the high degree of reliability demanded by

operations requires continued long-term testing and evaluation. This facet of the problem adds to the lead time of power sources certification and to their ultimate cost.

Battery reliability is an intensive function of time, numbers, and effort. As stated in the section on Uniqueness of Agency's Requirements, long-term performance is a prime goal of power sources. It can be stated unequivocally that reductions in funding or man power devoted to unglamorous battery testing programs must eventually be reflected in greater uncertainty as to performance parameters.

Policy, Political, and Organizational Aspects

Key considerations relevant to Program Adequacy are cited under this heading, but discussions of the various points is introduced elsewhere in this Report. This approach gives greater meaning and significance to the considerations and does limit repetition.

Policy:	(a)	Program approval versus task or project approvals
	[redacted]	25X1
Political:	(a)	Competitive attitudes
	(b)	"nih" factors
Organizational:	(a)	Communications
	(b)	Fragmentation of resources

RECOMMENDATIONS

Program

The Power Source Program should be an integrated effort involving all R, D, T & E capabilities and all consumers. "Coordination" at management levels does not accomplish this end nor does it insure full use of resources including those involved in subcontract situations. Responsibility for describing and assessing the present overall program (with recommendations) is the assignment of this Power Sources Panel; there is no basis to define and submit a Technical Program for approval.

Resources

Resources presently identifiable approximate [redacted] per year and about three man-years of in-house effort. The dollar value should be doubled both by supporting programs listed under New Initiatives and by increasing the level of effort to permit faster more thorough progress on active projects. Man power is grossly inadequate; the recommended level, if operations continue as at present, would be six to eight. A later recommendation presents another organizational approach and program scope which would require a different treatment of Resources.

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Policy

Policy questions in the past have been troublesome in the [redacted] area and in the granting of full Program approvals, particularly when parochial interests become involved.

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It is recommended that a unified Power Source Program be kept in a current form and that a review channel be established to act on questions of resource conflict, responsiveness to needs, acceptability of technical approaches and mission responsibilities. It is believed that the mechanism now being evolved through the Agency's R&D Board, as supported by the Technical Coordination Committee, can supply the required action channel.

Communications

The introduction and use of a procedure for direct working level use in describing active technical efforts is recommended. A suggested format is attached as Appendix B. This Brief is designed for technical communication and is not for planning or evaluation objectives; it should not become a staff document. In use the operating element would fill out said form upon the initiation of an activity, whether it be a contract, subcontract, or a major in-house study. Copies would be distributed to an established list of recipients to include all R, D, T & E elements and consumer offices. Revisions would be issued only at times of a major change in scope; a Final Brief would be issued to succintly describe the project accomplishment. The need to implement this recommendation vanishes, if any significant form of the Organizational Recommendation is implemented.

Organization

It is recommended that the Agency establish a centralized Power Source Activity. If one examines the conduct of Power

Source R&D in the Government, he invariably finds that a broad-based program is carried out by a multidisciplined, support element that operates across wide-ranging consumer sponsors. Rarely is the power source function an integral part of a system development. Examples can be cited in the nuclear weapons field at Sandia, in the ammunition development field at the Naval Ordnance Laboratory and at the Harry Diamond Laboratories, in the electronics field at the Army's Electronic Command, and in the space field at the Goddard, Lewis, and JPL Laboratories. It is observed that within TSD, as the Agency's largest activity in the field, that the power source function is horizontally organized within the Division.

A centralized Power Source Activity would permit the conduct of a well-integrated activity making optimum use of Agency human and fiscal resources. Further, it is probably the only mechanism whereby adequate test and evaluation capabilities could be established and supported that would be acceptable to the various consumers.

If a Power Source Activity is to be established the Mission would properly encompass responsibility for

a. conducting Research and Development

b. conducting Engineering, Test, and Evaluation

c. supporting Applications Engineering segments of system programs

d. maintaining an industry-wide data base

e. providing consulting services.

The Scope of such a capability would encompass a full program covering Propulsion Power, Auxillary Power, Emplaced Systems Power, Audio Power, and Micro Systems Power requirements and involve the technologies of Electrical, Electrochemical, Mechanical, Nuclear, and Solar capabilities.

The physical Location of the recommended Activity is relatively unimportant provided all segments are in a single integrated facility. The few thousand square feet of floor space should include a small wet laboratory. A test and evaluation capability involving five to eight people at an annual operating cost of perhaps [redacted] per year and requiring a facility investment of [redacted] would best be contracted.

Professional Resources to fulfill the responsibilities of the Activity would be eight to ten individuals representing a number of disciplines. Financial Resources should be not less than [redacted] annually with a mechanism being provided to support more costly, specific ventures.

The most difficult question is that of the Placement of the Activity in the Agency's Organization structure. Realistically, there appear to be three options:

a. a new organizational element established at the Office or Divisional level,

b. operating unit included as a Branch or Component in TSD, or

c. operating unit included as a Division in ORD.

The first option is rejected due to support staff requirements (empire/cost) and to a higher probability of communication problems with users. The advantage of starting with a clean slate in personal and interoffice relationships does not offset these disadvantages.

The Panel believes that should the recommendation of a centralized Activity be favorably received, then an in-depth assessment of its Placement in the Agency's structure should be made. Arguments, pro and con, relative to assignment in TSD or ORD are complex and analysis is judged to be beyond the immediate scope of this effort.

APPENDIX A

Solar Conversion. This technology is based upon the direct conversion of light, usually sunlight, to electricity. NASA with the expenditure of many tens of millions of dollars has established the National technology in materials and arrays and provides the substantive base for OSP requirements. Otherwise, to this Agency the photovoltaic (or solar cell) conversion is of prime interest in exploiting environmental energy for possible audio applications, Blackboxes, and emplaced systems. The new technology needed is operation in terrestrial situations and in situations of artificial light, normally of low intensity.

TSD and ORD are working closely toward the audio objectives. Sources involving terrestrial arrays are in use in OC. Frequent studies are made on special units for emplaced systems. Problems of concealment, fouling, and low power density requiring back-up storage batteries generally arise.

Batteries. Batteries convert chemical energy directly to electrical energy. The field has been widely researched so that bounds are known for energy density, power density, life and shelf characteristics. Since every application has its own set of trade offs, the best battery system must be selected for the

given application and then engineered into an acceptable device. It is rare that a battery power pack fully satisfies the user's goals; his system usually ends up power/energy limited.

It is very difficult to bound a power supply, battery program. The numerous possibilities coupled with the design trade offs in the using system define a complex program. Added difficulties enter in the costs to fabricate controlled items and in the area of test and evaluation where both numbers and simulation are required. The program does show heavy emphasis on improving energy/power density in systems compatible with the extended life objective. The other requirement of major influence is concealment. Work directed toward Blackbox requirements is minimal.

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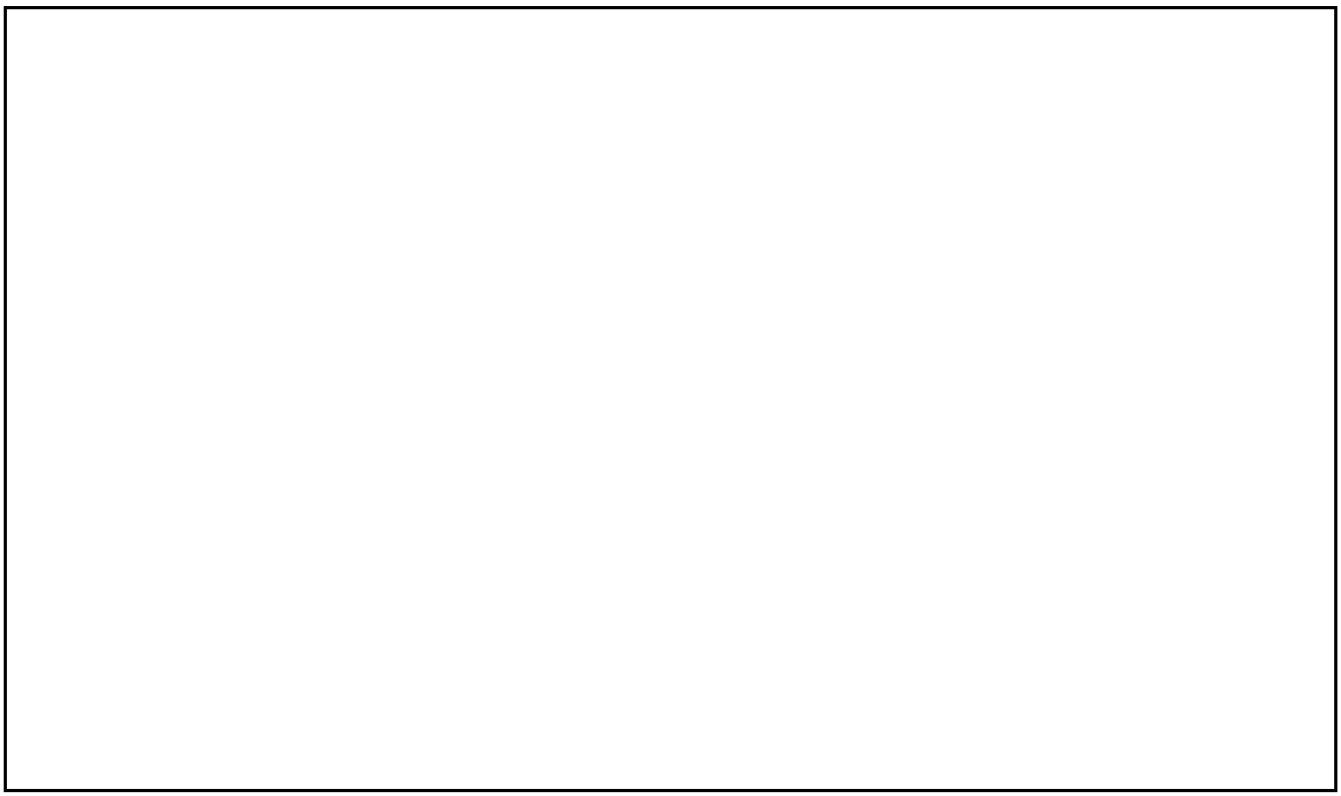

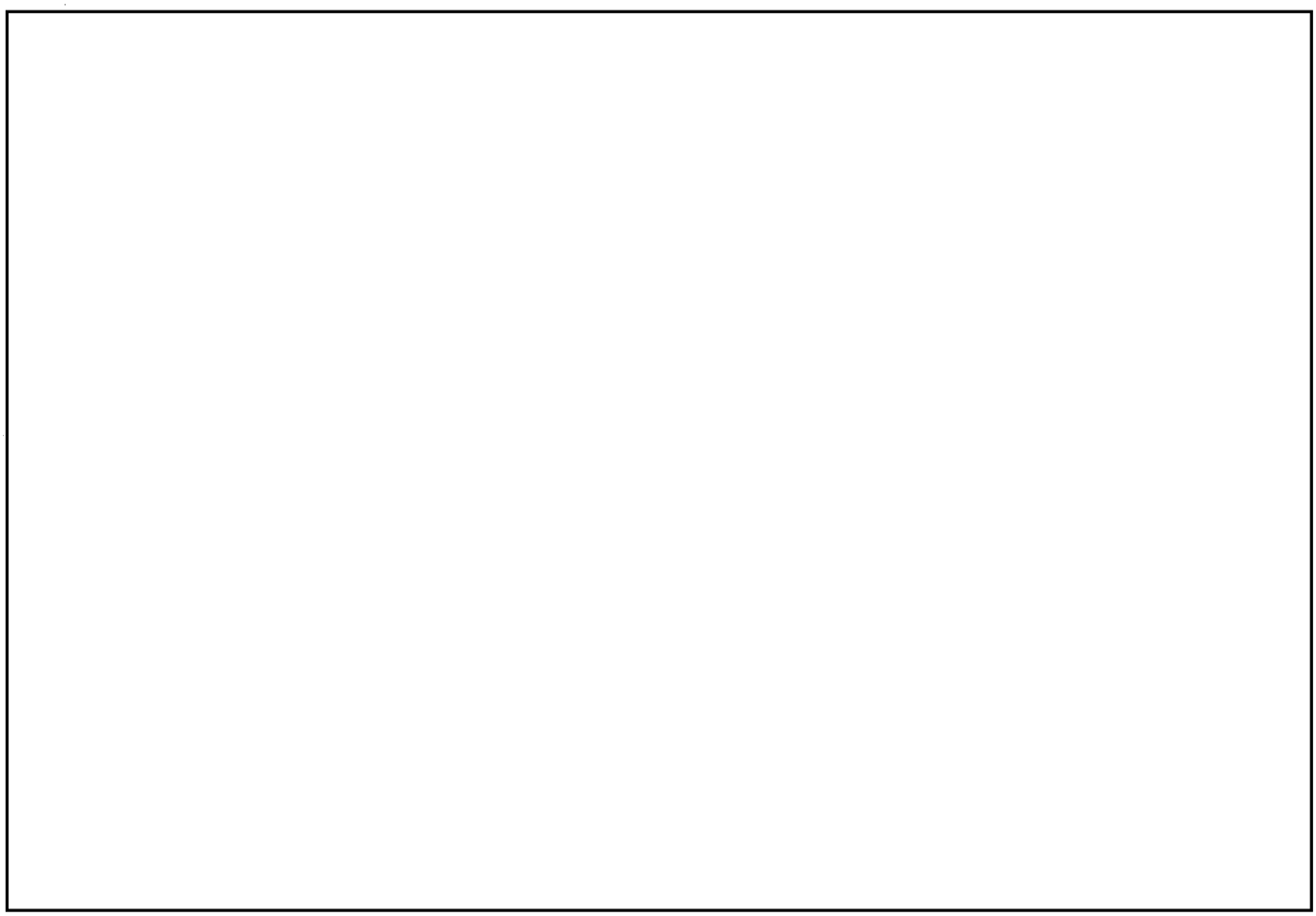

Environmental Energy. Many studies have been made on environmental energy sources. Levels of energy/power range from megawatts to microwatts using hydroelectric turbines, wind turbines, solar furnaces, solar cells, and many others. In this Agency's work operational constraints invariably limit the sources to low-grade heat or light. R&D in this area is frustrating due to incompatibilities between operational demands and the energy sources. Work will continue to be undertaken in response to sound technical approaches, however, for the possibility of getting "free" energy without being limited by

stored materials is most inviting. This area may eventually produce real capabilities for long life, unattended systems.

Biological Sources. No effort has been identified. These sources can have unique value for organically embedded devices, for example, Pacemakers. No real Agency need exists. "Nih" activities on implants will be monitored for possible future use; it is doubtful that any electrode system can be found to operate as a battery with body fluids within an animate object. Problems of poisoning and of body fluid imbalance can be expected from such systems which at best would be very low power devices.

APPENDIX B

Power Source Brief

Project Title | Project Officer

Sponsoring Office | Technical Field | Classification

Funding | Contractor | Principal Investigator

Project Goal

Technical Approach

Objective Specification

Project Officer | Date