Assessing the Health of Army Laboratories

Funding for Basic Research and Laboratory Capital Equipment

By John W. Lyons and Richard Chait

Center for Technology and National Security Po0licy
National Defense University

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John W. Lyons is a Distinguished Research Fellow at the Center for Technology and National Security Policy (CTNSP), National Defense University. He was previously director of the Army Research Laboratory and director of the National Institute of Standards and Technology. Dr. Lyons received his PhD from Washington University. He holds a BA from Harvard.

Richard Chait is a Distinguished Research Fellow at CTNSP. He was previously Chief Scientist, Army Material Command, and Director, Army Research and Laboratory Management. Dr. Chait received his PhD in Solid State Science from Syracuse University and a BS degree from Rensselaer Polytechnic Institute.

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Preface

In 1991 a Federal Commission appointed by the Secretary of Defense listed some characteristics of an effective laboratory[1]:

- Clear and stable mission
- Highly competent and dedicated workforce
- Highly qualified and empowered leadership
- State-of-the-art equipment and facilities
- Close relations with the user/customer
- Strong basic research component
- Budget stability
- Champion in senior management above the laboratory
- Strong ties to other laboratories inside and outside the government

The authors have been studying the Army Science and Technology Laboratories for several years to see what might be done to strengthen them.[2] In this paper we respond to requests from the office of the Army S&T Executive to address the adequacy of the funding provided to two of the above characteristics: equipment and basic research. The equipment issue is one of providing high quality research tools that enable the research staff to work at the frontiers; the funding of basic research concerns providing a strong program of fundamental and exploratory work. Having both excellent equipment and a foundation in basic research will help to ensure the technical quality of the products from the Army laboratories.

With the above in mind, this paper is divided into three sections, one for each topic of focus and a third for overall recommendations.

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[1] Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, *Report to the Secretary of Defense* (Washington, DC: Department of Defense, September, 1991).

[2] Findings have been published by the Center for Technology and National Security Policy, National Defense University, Washington, DC in the following: John W. Lyons, Joseph N. Mait, and Dennis R. Schmidt, *Strengthening the Army R&D Program*, Defense & Technology Paper 12 (March 2005); John W. Lyons, Richard Chait, and Duncan Long, *Critical Technology Events in the Development of Selected Army Weapons Systems: A Summary of Project Hindsight Revisited*, Defense & technology Paper 35 (September 2006); Richard Chait, John Lyons, Duncan Long, and Albert Sciarretta, *Enhancing Army S&T: Lessons from Project Hindsight Revisited* (book, 2007); John W. Lyons, *Army R&D Collaboration and the Role of Globalization in Research*, Defense & Technology Paper 51 (July 2008); John W. Lyons and Richard Chait, *Strengthening Technical Peer Review at the Army S&T Laboratories*, Defense & Technology Paper 58 (March 2009); John W. Lyons, Richard Chait, and Jordan Willcox, *Improving the Interface between Industry and Army Science and Technology: Some thoughts on the Army's Independent Research and Development Program*, Defense & Technology Paper 63 (June 2009).

Part I. The Distribution of Basic Research Funds

1. Introduction and Background.

Basic research, termed 6.1 in the Department of Defense (DOD) budget, is long-term, fundamental study in the sciences, including engineering science, motivated either by simple curiosity or by the need to solve a particular problem that existing knowledge cannot handle. A good way to think about basic and applied research is from Stokes[3]. In Figure 1, the vertical axis determines the extent to which the technical work is motivated by scientific curiosity with no particular application in mind. The horizontal axis indicates whether or not the work is driven by solving difficult practical problems. The plot is divided into two by two boxes but it could equally well have been drawn with the two axes being continua such that a particular project could be located anywhere on the graph. Stokes illustrated his idea by placing noted researchers in three of the boxes. Thus Bohr's work on the structure of the atom was curiosity-driven (pure basic research); Edison's work was said to be totally focused on the potential commercial uses of electrical illumination (pure applied research). Pasteur carried out fundamental or basic research studies motivated by his desire to treat diseases (use-inspired basic research). Much fundamental research today resembles Pasteur's.

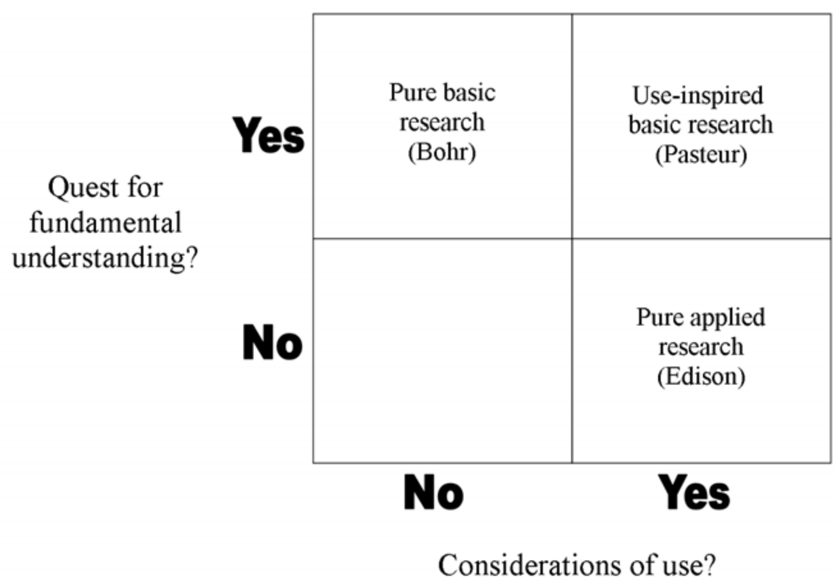

Figure 1. The Stokes two-dimensional model of research showing differences in motivation.

[3] D.E. Stokes, *Pasteur's Quadrant—Basic Science and Technology,* Brookings Institution Press, 1997.

Studies have shown that basic and applied research is essential to a strong technology development program. For example, Mark and Levine [4] in a study of the premier laboratories belonging to several federal agencies, including the Department of Defense (DOD), concluded that performing basic research was essential to the success of the laboratory. They found that basic research not only provides the foundation for the long-term mission but also enabled exploration into technology areas that were contiguous to the laboratory mission in case such areas later become highly relevant.

The DOD definition of 6.1 work is that it seeks to expand the frontiers of knowledge in areas thought to be of future interest, but not to address specific problems. However, a study by the National Research Council[5] suggested softening DOD's definition to allow work related to some specific applications that need additional fundamental knowledge. Much of the in-house DOD's basic research is in Pasteur's quadrant. A good deal of DOD's extramural basic research is less closely related to current problems, though the research is surely motivated by the known needs and problems of the Services.

2. Rationale for Basic Research.

For any laboratory there are many reasons, as noted above, to have some basic research. First, as noted above, is to push out the frontiers of knowledge in areas of potential interest. Next is to solve intractable problems that arise in the course of the laboratory's mission work. Then, the presence of fundamental, exploratory work in the laboratory will help keep the applied work at the state of the art. This may be through seminars or simply by cross talk in the lunch room. Basic work is in general publishable and hence puts the laboratory in contact with its peers around the world. Exciting results from basic research will attract collaboration with the best laboratories around the world. The work provides a window for the laboratory on new exciting areas being explored in the scientific community at large. Finally, the presence of 6.1 programs facilitates hiring new young graduates making the transition from thesis research to the challenges of the military laboratory. For these reasons every Army laboratory should have a meaningful component of 6.1 in-house research.

How much 6.1 is enough for the health of the laboratory? A figure often suggested by senior research managers across the community is about 15% of the total funding.[6] In the rubric for sizing the S&T funds in the general case this would be something like 15% basic research, 35% applied research, and 50% advanced development—not including customer money. This is a rising curve reflecting the increasing costs as one moves from fundamental bench studies to prototyping to full-fledged development activities.

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[4] H. Mark and A. Levine, *The Management of Research Institutions: A look at government laboratories,* NASA SP-481 (Washington, DC: NASA, 1984), 226.

[9]Assessment of Department of Defense Basic Research**,** Committee on Department of Defense Basic Research**,** National Research Council, Washington, D.C., 2005.

[6] A related figure is the amount of funding that should be available to the laboratory director to use at his or her discretion. The "Packard Report" on the Federal laboratories suggested that as much as 10% of the funding should be discretionary. See: *Report of the White House Science Council Federal Laboratory Review Panel* (Washington, DC: Office of Science and Technology Policy, The White House, May 1983).

Army laboratories are organized as follows:

- Army Materiel Command's Research, Development, and Engineering Command
  - Army Research Laboratory (ARL)
  - Aviation and Missile Research, Development and Engineering Center (AMRDEC)
  - Armaments RDEC (ARDEC)
  - Communications and Electronics RDEC (CERDEC)
  - Tank Automotive RDEC (TARDEC)
  - Edgewood Chemical Biologic Center (ECBC)
  - Natick Soldier RDEC (NCRDEC)
  - Simulation and Training Technical Center (STTC)
- Army Medical Command
  - Medical Research and Materiel Command (MRMC)
- Army Corps of Engineers
  - Engineer Research and Development Center (ERDC)
- Deputy Chief of Staff of the Army G-1 (Personnel)
  - Army Research Institute for Behavioral and Social Sciences (ARI)
- Army Space and Missile Defense Command
  - Space and Missile Defense Technical Center (SMDTC)

For a corporate laboratory such as the ARL, the ERDC, or the MRMC, this distribution would seem to be a good target. For laboratories focused on development—the RDECs in AMC, for example—a smaller percentage would likely suffice. The question then becomes, is there a level of 6.1 in a lab below which very little of significance can be done? This paper explores this question by first looking at the data for the Army laboratories and then providing an assessment with suggestions for improvement.

3. Data for the Army Laboratories.

Table 1 below shows the funding in fiscal year 2008 for the directly appropriated mission activities and the amount of that funding that is for basic research (6.1). All the laboratories have additional funds supplied by customers such as the acquisition community, other DOD agencies, and so on. These are not considered in the present discussion.

The calculation is based on total core funding without regard to whether that funding is spent in-house or on contracts or grants. The data from ASTMIS as supplied to us does not make that distinction. The development laboratories spend substantial amounts of their funding, especially their 6.3, extramurally. If we could take that into account their percentages would be higher. However, the data, though rough are useful for broad comparisons. Also note that the result for ECBC is not significant in that their funding comes almost exclusively from special programs at the DOD level. Two of the laboratories have no core 6.1 funds.

Table 1. Laboratory core funding from the Army S&T Management Information System (ASTMIS) for FY 2008.[11]

To compare basic research funding across the laboratories we use as the base the total core funding (6.1, 6.2, and 6.3).* The result is the following:

Laboratory	6.1 ($M)	Total Core ($M)	6.10%
ARL**	45.9	214	21.4
MRMC	25.7	162.5	15.8
ERDC	15.7	92.6	16.9
AMRDEC	9	230.1	3.9
ARDEC	2.7	100.6	2.7
CERDEC	1.8	321.2	0.6
TARDEC	4.8	189.5	2.5
ARI	3.7	26.7	13.9
ECBC	1.1	4.3	25.6
NSRDEC	2.3	71.1	3.2
SMDTC	0	50.5	0
STTC	0	25.5	0

* Basic research (6.1); Applied research (6.2); Advanced development (6.3).
** Only includes in-house R&D funds, not the grants at ARO.

4. Assessment.

The Army corporate laboratories—ARL, MRMC, and ERDC—meet the aforementioned criterion of 15% or more of their total funding for basic research. The ARL is the corporate laboratory of the Army Materiel Command and as such should have a large component of basic research. If one adds in the funds managed by the Army Research Office, now a part of ARL, the ARL dominates the Army's 6.1 programs. The MRMC of the Army Medical Command meets the criterion of about 15% of 6.1. The current challenges of post-traumatic stress disorder, traumatic brain injuries, suicide prevention, tissue and organ regeneration, and brain-controlled robotic prostheses will likely warrant more 6.1 funding for the MRMC.

The development-oriented centers—large and small—have relatively small amounts of basic research funding. Some argue that these centers should not perform basic research at all but leave that to the corporate laboratories and to the external programs. However, for the reasons advanced in the introduction above we believe there should be some basic research in all Army laboratories. Certainly numbers at or less than 5% are not adequate. The fact that a lot of this is In-House Laboratory Independent Research (ILIR) and is handled separately by the Office of the Deputy Assistant Secretary for Research and Technology makes the picture of more concern.

It is unclear if the lower numbers for these development centers are adequate for meaningful research; it depends solely on the nature of the work being funded. An investigator working alone can revolutionize a field, *viz* Einstein or Newton. A research group of just a few people can have a great effect on a division. To influence an entire laboratory there should perhaps be a group at every division doing primarily fundamental and exploratory research. Such a group should have at least some senior researchers supported by mid-level staff. A laboratory with six divisions would need about six groups, however small, doing 6.1 work.

5. Conclusions

There are many advantages to having basic research in all research laboratories. Perhaps the most important advantages are (1) solving very difficult problems in the course of doing mission work and (2) that performing exploratory research helps to ensure that the laboratory is working at the state of the art, and to maintain a creative environment. Another advantage is the improvement in the ability to hire accomplished young PhD investigators to the laboratory. Thus, all Army laboratories should have significant efforts funded by 6.1 money.

The distribution of 6.1 funds across the Army laboratories is skewed; in many labs, the level is far less than it should be. The numbers for the development centers are not adequate to support creative new approaches to difficult problems.

A critical factor is the attitude of the senior management of each laboratory or center. If the management believes strongly in the value of a basic research program then it is more than likely that any 6.1 funds provided to that laboratory will be properly invested.

Part II. Funding for Laboratory Capital Equipment

1. Introduction

To complement recent studies aimed at strengthening the Army Science & Technology (S&T) program (see references 2-6 in Part I), the Army S&T Executive requested an assessment of the recapitalization of the infrastructure of the Army laboratories. Infrastructure is divided into three components: new buildings or major renovations to buildings, large facilities such as wind tunnels, and equipment that can be installed in ordinary laboratory modules. Ordinarily, buildings and major facilities are funded through appropriation requests for Military Construction (MilCon) funds. Laboratory requests for MilCon funds are prioritized against all other Army requests; typically, the laboratories lose out in the competition. We elected to study only the funding of laboratory equipment. The technology of laboratory equipment evolves rapidly in step with that of science and technology as a whole. In order to conduct state-of-the-art basic and applied research, the equipment must be also at the state of the art. As noted earlier, this means that equipment must either be continually updated or replaced with new versions.

2. Definitions and Uncertainties.

The situation is not entirely clear with regard to the basic available information. We began by seeking clear statements as to what constitutes capital equipment (e.g. the necessary useful life and the minimum initial purchase price). Various sources we consulted agreed that the useful life is more than 1 year, but the minimum purchase price required for an item to be classified as capital equipment varied widely.

In OMB Circular A-110 (revised and amended 9/30/99 Appendix A, Subpart A.2, Definitions) relating to contracts and grants, capital equipment is defined as follows:

> Equipment means tangible nonexpendable personal property including exempt property charged directly to the award having a useful life of more than 1 year and an acquisition cost of $5000 or more per unit. However, consistent with recipient policy, lower limits may be established.

Various other OMB and GAO documents require 2 years or more of useful life but fail to set a minimum dollar value. By “capital equipment” it is meant that the item is put on the books as an asset. It is not clear what rules apply to putting an item on the books. We contacted two Army laboratories to get information beyond the tabulated data from the DAS(RT) office. The latter included core funding data from the Army S&T Management Information System (ASTMIS) (see table 1). We also had data from the submissions for the Army Research and Development Laboratory of the Year.

In most bulletins and circulars, information technology (including automated data processing) equipment is treated separately. These assets are, in general, not included in this discussion.

There is no tax advantage to depreciation of an asset in the government, but, by use of a working capital fund, depreciation is a means of spreading the cost of an item over its predicted life. Of our government respondents, only two have working capital funds (NRL and NIST). In the requirement to list lab equipment in the submissions to the 2009 Army Research and Development Laboratory of the Year competition, only items costing over $100,000 were reported. This makes it very difficult to compare Army data with any other laboratory, either government or private sector. Therefore, in this paper we can only make broad generalizations with ill-defined uncertainties. However, we believe we can draw some conclusions. Also, given the shortcomings of the data available to us, we urge that a necessary step is to set a realistic cost basis for Army purchases and seek to get a constant basis with other DOD and government laboratories. This may be difficult or impossible but it is worth a try if the Army is concerned enough.

In the competition for the Army Research and Development Laboratory of the Year, the Army laboratories are divided into three categories (corporate research laboratories, large development laboratories, and small development laboratories) for assessment. However, the evaluation factors are consistent across the categories. One of these categories is laboratory equipment. The submissions include data on spending for this equipment. Laboratory equipment is taken to mean items not normally provided in every laboratory and costing over a certain minimum amount. (In the data call for the Army Laboratory of the Year this is set at $100,000 presumably to focus on only the most costly investments.) In addition, this category includes items that can readily be installed in an ordinary lab module. Examples are molecular beam epitaxy machines, chromatograph/mass spectrograph machines, and a variety of other analytical tools—X-ray, magnetic resonance, and various testing equipment.

Information on the spending for laboratory equipment is presented below for Army and, other Service Laboratories, another government laboratory, and two industrial laboratories. The results are assessed, conclusions drawn, and recommendations made.

3. Data from the Army Laboratories.

The data for equipment spending are taken from the tabulations in the submissions for the Army Research and Development Laboratory of the Year 2009 and are averages for the spending reported for the previous 5 years (presumably FY 2004 through FY 2008). The data for total in-house mission (core) funding are for FY 2008 and have been taken from the ASTMIS files. The data do not show whether equipment is bought using base funding or customer money. In case of the development laboratories, it appears that some equipment is provided by the customers and may not be included in the figures. Spending on capital equipment may vary from year to year depending on the specific needs of a laboratory's projects. Some pieces of laboratory equipment are very expensive (e.g. high-vacuum apparatus for molecular beam epitaxy and other such applications requiring the laying down of thin films on substrates); such devices may cost upwards of $1M. Current work in nanotechnology generally requires clean room conditions along with high-vacuum equipment. However, such investments usually do not occur every year. In the table, we have taken the 5-year data and divided it by five to afford an average yearly figure.

Table 2 shows that ARL and ERDC spend in the range of about 10% of their core funds for laboratory equipment. MRMC is a little less. The RDECs and other development centers spend less than 2.5% of their core funds. Note that the core funding is for FY2008 whereas the equipment funding is for an average over 5 years including FY2008. Recall that these numbers are based on only the most expensive items—over $100,000.

Table 2. Army Spending on Lab Equipment

Corporate Research Labs	Cap Equip*	Core funds	%
Army Research Lab	$23M	$214M	10.7
Engineering R&D Center	18	162.5	11.1
Medical Research and Materiel Command	6.6	92.6	7.1
Res. Dev., and Eng. Ctrs (large)			
Av. Missile RDEC	3.4	230.1	1.5
Armaments RDEC	5.5	100.6	5.5
Communications and Electronics RDEC	2.3	321.2	0.7
Tank and Automotive RDEC	4.7	189.5	2.5
Smaller Laboratories			
Army Res. Inst.	0.04	26.7	0.1
Edgwd Chem. Biol. Ctr	3.8	4.3	88.4
Natick Soldier RDEC	2.2	71.1	3.1
Space and Missile Dev. Tech. Ctr	2	50.5	3.9
Simulation & Training Technology Ctr	**	25.5	0

Source: Submissions to the Army Research Development Laboratory of the Year for 2009 counting only items valued at over $100,000

* Divide the 5-year total for equipment by 5 and then by the total in-house funding for FY2008.

** None reported

Customers provide some equipment for their projects and on some occasions the equipment is turned over to the laboratory when work is complete. We were unable to obtain good estimates for this funding support. To the extent that customers do not provide funding for equipment and that the laboratories' capital equipment is then used for sponsored work, the percentages will be diluted.

Since equipment is used in all activities within the laboratories the total in-house numbers may be a better indicator. On this basis ARL and ERDC have numbers in the 4–9% range; all the others are lower.

4. Data from Other Laboratories

The data that follows was collected from several non-Army laboratories to provide comparisons. In every case there are variations in definitions or in completeness of information. Nonetheless, the information provides something of a yardstick for comparison.

Air Force Research Laboratory.

The Materials and Manufacturing Directorate at Wright Patterson Air Force Base buys its equipment from its 6.2 and 6.3 accounts. The level of purchases from these accounts ranges from 2–5%. The 6.1 is provided from the AFOSR and is not used for equipment. AFRL does not have a means to depreciate these expenses.

The Directed Energy Directorate at Kirtland AFB . The Directorate had an income of \$325M in FY2009 of which \$143M is mission funds. Management estimates that about \$50–80M of the total is spent in house. About \$1M is spent on equipment—or from 1.25 to 2%. In addition, they receive some equipment from customers but its use is restricted to the customers' projects.

Naval Research Laboratory. The NRL spends about \$15–16M each year on depreciable laboratory equipment. The total in-house funding for NRL is about \$700M. The S&T core funding is \$180M consisting of 6.1 and 6.2 only. When asked whether this S&T base should be used when calculating the percentage the answer was: no, the total in-house funding should be the basis. The percentage is then 15.5/700 = 2.1%. To compare to the Army data we compute the NRL figure based on core funding. This yields 8.6%, comparable to ARL and MRMC.

The total replacement value of the NRL lab equipment is of the order of \$1B so the recapitalization rate is over 60 years.[7]

[7] Capital equipment is purchased through the Navy's working capital fund (WCF). The fund is repaid by depreciation annually, shown on NRL books as part of overhead expenses. The size of the NRL overhead account is controlled by external authority. Thus, the amount of depreciation that can be charged is also controlled. Some flexibility has been provided by Section 219 of the National Defense Authorization Act for FY 2009. This legislation gives Defense laboratories 3% of appropriated funds for use at the discretion of the director. Presumably this authority could be used to purchase equipment as expense items apart from the WCF. Depreciation life varies by class of equipment. Some additional equipment is supplied by NRL's customers. The exact amount is unknown.

National Institute of Standards and Technology. NIST provided 4-year figures for equipment purchases against their Congressional appropriations for their laboratories and, separately, against reimbursable funds (RF). NIST purchases equipment in two ways: by expensing all costs in the year of purchase, and by use of its working capital fund to spread costs over projected lifetimes. Each area devotes about 3% of the total NIST budget for an aggregate total of about 6%. This percentage is close to the level for ARL, MRMC, and NRL. These numbers do not include purchases in the category ADP (automated data processing). NIST argues that this category is largely for office equipment.

Two Industry Laboratories. We consulted two laboratories that conduct research into electronics and related subjects. One reported a level of 1.5–25; the other reported a percentage more akin to the Army corporate laboratories.

5. Recapitalization Rate.

We have very few data on the rate at which capital equipment is replaced—the recapitalization rate. The ARL estimates its rate as 68 years; i.e., at the current rate of spending on equipment it would take 68 years to replace it all. This computes to a replacement value of about $1.3 billion. The Naval Research Laboratory values its equipment at about $1 billion for a rate of 64 years. The ARDEC similarly gives a replacement value of about $1 billion for a rate of about 180 years!

6. Conclusions.

As was the case for doing basic research**,** there are many advantages to having a well-equipped laboratory. It helps in hiring and maintaining an excellent work force. First class research equipment not only is required for carrying out the work but also it enables a quality of work that is essential for supporting the soldier. Having such state—of-the-art equipment will attract collaborators from outside laboratories.

The data are somewhat sketchy and rest on various definitions that we were unable to clarify. We can say that the level of spending on laboratory equipment in corporate laboratories is fairly similar—ranging from 5 to 10 or 11%. In comparison the engineering oriented research centers spend much less—in the area of 1–3%. Figures for NRL and NIST are comparable to the corporate Army research labs

If the Army wishes to establish a sound basis for program planning and budget we believe a detailed study involving an in-depth accounting process would be necessary.

Part III. Recommendations

1. *All Army laboratories should have adequate funding for basic research and for the laboratory equipment needed to do first-rate work.* This recommendation includes the development centers. Basic research helps provide an innovative climate and will provide the means to keep the lab at the state of the art. Basic programs will help attract bright young new PhDs to the lab. One cannot do world-class technical work with outdated laboratory equipment. This is especially true in the newly emerging fields of study.*

2. *Funding with 6.1 money should be based on carefully conceived proposals from qualified investigators.* To avoid using 6.1 money for projects that are not fundamental and exploratory, management should scrutinize proposals and make sure they are based on sound reasoning and will be staffed by very capable individuals.

3 *ASAALT should require significant 6.1 funding for all Army labs.* One way to think about how much is enough is to assume that every research division should have some forward-looking fundamental and exploratory work—at least two senior investigators. The ILIR funding is insufficient to meet this recommendation.*

4. *ASAALT should establish a clear set of guidelines for managing laboratory capital equipment.* Definitions should be standardized, preferably in concert with the DDR&E office so that fair comparisons can be made across the services. It appears that laboratory managers do not focus sharply on investment in capital laboratory equipment.

5. *For a sound basis for planning and budgeting an in-depth study involving professional accountants will be necessary.* The uncertainties in defining what is meant by capital equipment and sorting it out from facilities upgrades and the like means taking a careful look at each tem and deciding whether it is or is not capital equipment. This would comprise an audit of the books.

6**.** *Basic research and capital equipment funding should be emphasized topics in conducting peer reviews of the laboratories.* We also suggest that additional approaches include placing both items in performance reviews of managers and in making them special topics to be covered in the submissions to the Army Research and Development Laboratory of the Year competition.

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*Consideration might be given to injecting more 6.1 funds into the in-house laboratories. In addition to direct budget enhancements, a possibility is to allow the laboratories to compete for support from the Army Research Office. The Office of Naval Research and the Air Force Office of Scientific Research both provide funds competitively to their in-house laboratories. This change in ARO operations would have to be very carefully planned and executed and would likely require an increase in ARO's budget.