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Folder Title:
Climate Change 1990 [6]

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STUDY: BUSH CAPITAL GAINS PROPOSAL WILL REDUCE FEDERAL BUDGET

President Bush's proposed capital gains tax cut will increase federal revenue by $185 billion over the next ten years and most of the new revenue will come from wealthy taxpayers according to a study by the National Center for Policy Analysis.

"It's a win-win proposal which will produce a painless reduction in the federal deficit," said Gary Robbins a former Treasury Department economist who coauthored the study. "People who sell assets will get to keep more income and the government will get more in taxes."

Under the Administration's proposal, the effective tax rate on capital gains income would be reduced by as much as 19.6 percent, depending on the length of time an asset is held. The study says that the tax cut will make investment more attractive and will stimulate economic growth. As the economy grows, government revenues will grow as well. Specifically,

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- The Bush proposal will cause the nation's output of goods and services to increase by $623 billion over the next ten years.

- Aftertax personal income will be $182 billion higher by the year 2000, increasing about $15 billion per year.

- Increased federal revenue will grow to $65 billion by 1995 and $185 billion by the year 2000.

- State and local governments will collect $106 billion in new taxes over the decade.

"Most of the new revenue will come from wealthier taxpayers," said Robbins. "The capital gains tax cut is a very progressive way of reducing the federal deficit." According to the study:

- Taxpayers with an income of $75,000 or more will pay 49 percent of the additional personal income tax revenues.

- Taxpayers with an income of $30,000 or more will pay 93 percent of the additional personal income tax revenues.

The study says that capital gains forecasting has become a "political football in which forecasters selectively consider some economic effects while ignoring others, and suspiciously alter their forecasting assumptions."

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Congress's Joint Committee on Taxation (JCT) and the Administration's Department of the Treasury have both released forecasts more pessimistic than the NCPA forecast. "Both agencies are ignoring the dynamic effects of a tax cut on investment and economic growth," said Robbins. "If the 1980s taught us anything, we learned that taxes affect behavior."

Robbins said the NCPA forecast considers all economic effects and is based on very moderate assumptions.

SCIENCE
&
TECHNOLOGY
AND
THE PRESIDENT

October 24, 1988

A REPORT BY

THE CARNEGIE COMMISSION ON SCIENCE, TECHNOLOGY, AND GOVERNMENT

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EXECUTIVE SUMMARY

1. The Carnegie Commission on Science, Technology, and Government was established in April, 1988 to assess the process by which the government incorporates scientific and technical knowledge into policy and decisionmaking. The Commission is made up of individuals with broad experience in government and in science and technology.

2. Science and technology, effectively mobilized, can help the President achieve his Administration's goals. That mobilization can best be accomplished by bringing science and technology (S&T) into the highest levels of government. The Commission has therefore focused its attention first on how S&T knowledge and advice can help the President deal with S&T related matters in the transition period and beyond.

3. Some of the issues involving S&T that will come up include: national security (new weapons, arms control, SDI), health (health costs, AIDS, drugs), large S&T projects (the superconducting supercollider, the High Speed Civil Transport), the environment (acid rain, ozone depletion and greenhouse effect), economic competitiveness, energy and nuclear materials, and the S&T enterprise (science education, academic research and the defense technology base). Other issues are certain to emerge.

4. The President will need the help of a senior staff assistant to respond to his needs by providing independent counsel in matters involving S&T -- for advice, for assistance in policy formulation, budget preparations, policy and program implementation, responding to emergencies, and for early warning of major S&T developments.

5. The Commission recommends that the President upgrade the existing position of Science Adviser to an Assistant to the President for Science and Technology. The appointment should be made early in the post-election period so that the Assistant can participate on the transition team and handle S&T questions relating to policy directions, budgetary choices, the organization of the Executive Office staff, and the identification and review of candidates for major Presidential appointments to S&T posts in the Executive Branch. The Assistant should propose S&T qualified individuals to serve on Presidential task forces dealing with policies and programs and should organize *ad hoc* expert groups on selected S&T issues when requested.

6. The Assistant should have a strong and formal relationship with the National Security Council, the Domestic Policy Council, the Economic Policy Council, and the Office of Management and Budget.

7. The Assistant would also be Director of the statutory Office of Science and Technology Policy (OSTP) within the Executive Office of the President. The

OSTP should be strengthened. The four Presidential appointments to the positions of Associate Director of the OSTP should be made, and the OSTP staff will need to be increased. The Associate Directors should have policy functions as well as diversified expertise. They should be closely coupled with other parts of the Executive Office, including the NSC, through joint arrangements. The OSTP should have the resources to commission outside analytical studies.

8. The President and his Assistant must have the ability to call on the national S&T community for help and to have the collective judgments of broad-gauged experts drawn from different facets of S&T. The Commission recommends that the President appoint an outside group of highly qualified and respected science and technology advisors to report to him through its chairman, the Assistant for Science and Technology. The members should be willing to devote a substantial portion of their time to its work.

9. The Commission stands ready to help the President and his Assistant for Science and Technology during and following the transition period.

I. INTRODUCTION

This paper by the Carnegie Commission on Science, Technology and Government was prepared to assist the incoming President and his staff as they deal with matters involving science and technology (S&T) during the transition period and thereafter [1]. The paper:

- discusses the President's needs during the post-election period;
- highlights key S&T related issues that will require Presidential attention early in the new Administration;
- describes the major functions for the President's S&T staff; and
- outlines organizational requirements for obtaining S&T advice.

The Commission was established by Carnegie Corporation of New York in April 1988 to assess, over a three to five year period, the process by which the government brings S&T knowledge into policy and decisionmaking. Rapid and pervasive transformations resulting from developments in S&T have imposed critical burdens on this process [2].

While the Commission's mandate covers all parts and levels of government, it has given priority attention to how the President gets S&T advice and assistance. The organization of this function can influence the entire Federal decisionmaking system and the ability of the nation to use S&T to further military security and domestic well-being.

II. THE PRESIDENT'S NEEDS DURING THE TRANSITION

Even before his inauguration, the new President will have to

- set initial policy priorities for the new Administration;
- resolve critical budgetary questions concerning S&T investments in defense, space, health and other major programs that will affect his first Budget Message to the Congress;
- make several dozen key technical appointments to the Federal departments and agencies; and
- organize the White House and the Executive Office staffs.

Scientific and technical expertise and advice are relevant -- even necessary -- to all of these undertakings. A senior staff assistant who is compatible with the President and his other key staff advisers can be an important contributor to Presidential decisions during the transition period. The incoming President will want to be as knowledgeable as possible about the issues and have a staff capable of providing a confidential, independent, dependable and continuing source of S&T expertise.

The Commission believes that the President should upgrade the existing position of Science Adviser and appoint a senior staff member, with the title of Assistant to the President for Science and Technology, early in the transition period. The person appointed must be capable of obtaining and providing advice on these immediate tasks, have the full confidence of the President, have the respect of the S&T community, and have the breadth to assist the President as he addresses a substantial agenda of issues. The Assistant would also serve as the Director of the statutory Office of Science and Technology Policy (OSTP).

Many significant budget decisions will have to be made by the President during the transition and in the early days of his Administration. A number of them will require judgments on the S&T aspects of programs. Research and development expenditures are approximately 25% of the discretionary budget. The Assistant should work with the new director of the Office of Management and Budget on major budget issues involving S&T.

The Assistant should be a member of the group that recruits for key Presidential appointments calling for technical competence. Appendix B lists some sixty important positions requiring Presidential appointments that also require S&T qualifications. The people involved in personnel searches are typically not knowledgeable or experienced in identifying such persons. An Assistant for Science and Technology who is highly regarded by the President and the technical community can play a critical role in proposing and reviewing prospective candidates, and persuading distinguished individuals to accept high-level positions. In carrying out this task, the Assistant could enlist the help of organizations such as the National Academies of Sciences and Engineering, the Institute of Medicine and the American Association for the Advancement of Science.

The President may wish to convene special task forces during the transition period to address immediate and longer-range policy issues. Where appropriate, the Assistant should be asked to recommend persons competent in S&T to serve as members of these task forces. When requested by the President or the transition team, the Assistant should also organize *ad hoc* expert working groups to probe S&T matters in depth.

> **The Commission recommends that the President appoint an Assistant for Science and Technology very early in the transition and that the Assistant be a member of internal staff groups addressing policy and budgetary issues and advising on Presidential appointments to positions that require a scientific or technical background.**

> **The Commission further recommends that the Assistant be asked to propose technically qualified persons to serve on Presidential task forces dealing with particular areas of concern and to convene *ad hoc* groups of experts to examine selected S&T issues.**

III. PRESIDENTIAL LEVEL ISSUES INVOLVING SCIENCE AND TECHNOLOGY

In recent years, there has been a substantial increase in the number and scope of issues coming before the President whose resolution require S&T knowledge and informed professional judgment. They stem from the acceleration of scientific knowledge and technological development, from the opportunities these developments offer, and from an increased understanding and awareness of their economic and societal consequences.

Beginning immediately and throughout his administration, the President will have four main areas in which he will need S&T advice. The first embraces the scientific and technical aspects of space and national security, including arms control issues. The second concerns civilian technology and economic competitiveness. The third involves biomedical questions, including health and drug abuse, and the environment. The fourth is the S&T technical base -- the entire research and development apparatus, basic science and generic technology; and science and engineering-education. Many individual decisions affect more than one of these areas.

Among the critical S&T-related issues facing the next President are the following:

National Security

Many national security-related policies have interwoven technical, political and military dimensions:

New Weapons Systems Requirements. There is general agreement that the recent build-up in the Defense department has been designed for an annual operation level that is substantially higher than the level of $300 billion agreed for future expenditures by the Congress and the present Administration. As new weapons systems now come on-line, the President will face major decisions on the balance between strategic and conventional forces and between weapons procurement, operations and maintenance, force structure, and sustainment capabilities.

Strategic Forces. It will be necessary to restructure and modernize the strategic forces to incorporate new weapons technologies. How can the changes be made to ensure that these forces are adequately survivable? Do they enhance our security and do so in the most economical way? How can capabilities and objectives be better matched?

Strategic Interaction with Conventional Forces. If strategic forces were to be reduced by 50% under a START agreement, what changes would be needed in the level and mix of our remaining strategic as well as conventional forces? For example, to what extent and in what way should technological opportunities, such as high precision weapons, be exploited?

Arms Control. There are technical possibilities for unilateral verification of arms control agreements in addition to cooperative and more intrusive means of verification. How should these possibilities affect U.S. positions and goals in negotiating arms control treaties? The Strategic Defense Initiative program is a critical part of the arms control debate. Its goal requires changing the balance between defensive and offensive strategic forces. Is this goal technically and strategically viable?

Intelligence. In the past, White House leadership has been important to the development and continued improvement of new technologies for surveillance. Are there new possibilities for collecting and analyzing information? What is the value of additional technical intelligence capabilities in relation to their cost? How could new intelligence technologies open up opportunities for viable phasedowns of strategic and conventional weapons systems?

Space policy

U.S. dominance in space peaked with the Apollo manned lunar landings and the Viking unmanned exploration of Mars. It has since declined. The President will have to make critical decisions about the space program.

Space goals and initiatives. Priorities have to be set among the various expensive programs. Which major new initiatives -- planetary exploration, earth science, or manned missions to the Moon or Mars -- should the President support? Should any of these be cooperative programs with other countries? Will the space shuttle be able to justify its costs over time?

The Space Station. Funding the Space Station -- the logical next step to prepare for manned exploration -- may crowd out NASA's smaller scientific and operational programs. The President will need to decide whether to fully fund, stretch out, or modify the program.

Launch Capability. Launch capability for unmanned missions has deteriorated. How do the military and civilian programs obtain a balanced, mixed fleet of launchers?

Civilian Space Programs. While the U.S. did the pioneering work in civilian space applications, we are losing that lead. U.S. leadership in satellite communications is threatened by the Europeans and the Japanese. The French earth observation satellite is outperforming the American unclassified version, and French and Chinese launchers are gaining in the commercial satellite launching market. Should the government take a more active role in the development and promotion of civilian space applications?

Civilian Technology and Economic Competitiveness

The international competitiveness of American industry has suffered serious erosion. One of the underlying causes -- though only one of several -- is a loss of American leadership in important product and process technologies. The critical deficiency is not in research but in failure to achieve fast and effective commercialization of scientific and engineering advances. The hard task facing the government is to find ways to induce industry to abandon short-sighted management practices, without interfering in the details of business decision-making. Policy will have to go beyond the support of R&D to such complex goals as achieving a lower cost of capital for investment, stimulating long-range improvements in manufacturing technology, and creating a labor force with skills and motivations adequate for the modern competitive world. S&T machinery must interact with economic and fiscal policy.

Health

Health care accounts for over 11% of the U.S. GNP, but there is ever increasing dissatisfaction with the balance of costs and benefits. These conflicts will surely be aggravated for a variety of reasons including the aging of the U.S. population, the rapid evolution of new but more costly technologies (like the new artificial kidney and the magnetic resonance scanner), a host of new ethical dilemmas, and increasing expectations that technology can offer and society will pay for alleviation of all disease.

Meanwhile, substance abuse is a festering wound that threatens the fundamental tenets of civility, compounded by its further consequences in crime and in the spread of AIDS and other infections.

Scientific research related to health care is a legitimate source of pride in the U.S., but it constitutes barely 3% of the investment in care alone. Are expenditures in health care, disease prevention and research in proper balance and coherence?

Environment

Air Quality. Acid rain pollution has been a contentious issue between different geographic areas of the country. Ozone depletion in the upper atmosphere has focussed attention on the impact of apparently benign gases, such as chlorofluorocarbons, on the atmosphere. The increase in infrared-absorbing gases such as carbon dioxide and methane seems to be reinforcing concerns about a "greenhouse effect" that is causing global warming. These problems go beyond our borders, and require international agreements and Presidential attention.

Waste Disposal. Toxic chemicals and medical waste attract public attention, but the waste disposal problem is much broader. What more should be done to anticipate and reduce environmental threats?

Large-Scale S&T Programs

Large science and technology programs have become costly discretionary items in the budget. Many of them start out as relatively small items in a given agency's budget and do not appear to raise significant questions. Because these projects are generally sponsored by different agencies, their relative priorities are often not weighed systematically. The opportunities for international cooperation tend to be neglected. Some examples include:

New Aerospace Transports. The Air Force is developing technology for a National Aerospace Plane (NASP). This program -- currently budgeted to receive approximately $100 million per year -- is aimed at developing a Mach 25 aircraft that can go into space. At the same time NASA is pursuing the Mach 2.5-5.0 High Speed Civil Transport (HSCT), also scheduled to cost $100 million per year. The project competes with Japanese and European efforts.

The Superconducting Supercollider. Site selection is proceeding on this high energy accelerator that is expected to advance the field of fundamental particle physics. The project is sponsored by the Department of Energy. Congress has funded the program at a relatively low level, thereby deferring the decision to build to the next President. The program will eventually cost $5-6 billion.

The human genome program. The Department of Energy and the National Institutes of Health are co-sponsoring an ambitious, long-range effort to map the structure of the human genome. The long-term cost could reach $2-3 billion.

Scientific and Technical Education and Research

Scientific and technical education. The current quality and extent of science education are seriously inadequate in meeting the nation's need for an informed citizenry and for technological growth in the decades to come. While the states are mainly responsible for elementary and secondary education, Federal leadership is needed for upgrading curricula, development of tests, improvement of teaching, and meeting the special needs of women and minorities. At the college and graduate level, more American students are needed, particularly in engineering. In addition, the Federal government should find ways to encourage technical upgrading of those already in the work force.

Scientific and Technical Research. There needs to be stronger support from Federal research grants and contracts for basic research at universities. University research facilities are well behind the industry norm, reducing the opportunity for cutting-edge research. In considering the cost and value of "big science and technology" projects, the President will need to take into account the appropriate balance between them and investigator initiated "small science" -- the backbone of basic science and of S&T graduate education. To what extent should some of these large-scale projects be carried out cooperatively with other countries?

Government Technical Personnel.

The success of the next Administration will depend heavily on the quality of people it can recruit for technical positions. It is generally agreed that the quality has eroded. Low government salaries, conflict of interest laws, and lessened respect for civil servants may all contribute to the problem. Can recruitment policies and hiring procedures be modified to attract excellent technical people to managerial positions?

IV. SCIENCE AND TECHNOLOGY FUNCTIONS SUPPORTING THE PRESIDENT

The Assistant for Science and Technology wears two hats: that of a senior member of the White House staff, and that of Director of the statutory Office of Science and Technology Policy. In both capacities, the Assistant should perform the following principal functions drawing on the resources of the OSTP staff and outside consultants:

Advice: advising and assisting the President and his staff

Policy: participating in the formulation of policy involving S&T

Funding: advising on the priorities and funding of S&T

Implementation: tracking of S&T related policy implementation

Early Warning: alerting the President to developments in S&T and their policy significance

Emergencies: responding to emergencies such as electricity blackouts, technoterrorism, computer breakdown, natural disasters.

Matters coming to Presidential attention that involve S&T usually have one or more of the following characteristics:

- they reach across or beyond the interests and responsibilities of several departments and agencies;
- they have major budgetary or policy implications;
- they have significant national security or foreign policy dimensions;
- they have particularly high public visibility.

Advising the President

It is not possible to differentiate sharply between the roles of the Assistant and the Director of OSTP. The Assistant acts in an individual capacity as a member of the President's inner staff to respond to his day-to-day requests for advice and assistance and to integrate all S&T inputs and relevant considerations in making suggestions and recommendations to the President.

Science and technology advice and assistance to the President can take the form of weighing conflicting technical arguments, presenting policy alternatives and options, recommending choices and priorities, and evaluating scientific or technical solutions to problems.

An important function of the Assistant is to foresee opportunities and problems. As President Ford has noted in this context, Presidents don't like surprises. At the same time, the Assistant must balance his attention to longer range issues with current and ongoing problems and opportunities.

The Assistant can help the President in his meetings with the heads of foreign governments. Presidential meetings with the leaders of the Soviet Union, India, Japan, Korea and Taiwan have featured S&T initiatives and agreements. Such agreements often symbolize U.S. technical leadership, while serving broader foreign policy objectives.

Although the Assistant is selected from the S&T community, it is should be stressed that he is not a lobbyist for that community. Thus, the President can rely on the Assistant to monitor the health of science and engineering and to identify measures needed to strengthen the national S&T base, working closely with the National Science Board. In the past, some members of the S&T community have erroneously expected the Assistant to be their spokesperson. There have also been occasions when the Science Adviser has been viewed within government as a special pleader for science. The performance and effectiveness of the Assistant must challenge and transcend that misperception.

The departments and agencies will provide much of the help the President needs on S&T matters. While some may view the Assistant and the OSTP as a substitute for S&T competence in the agencies, they function most effectively when the agencies have good technical leadership and staff. In both roles, the Assistant works with departments and agencies to negotiate compromises or agreements among conflicting interests and to point them in new directions, linking them to Presidential concerns.

Working with Cabinet-level Councils.

The Assistant should work closely with other senior members of the President's staff and with Cabinet members as they come together in the National Security Council, the Domestic Policy Council, the Economic Policy Council, the Council of Economic Advisers, the Council on Environmental Quality, and other Executive Office mechanisms that may be established.

The National Security Council (NSC). In carrying out its integrative role, the NSC must involve specialized and sensitive understanding of modern military technologies and their future evolutionary prospects.

The NSC has added a number of staff members with technical training, many directly from the military services. However, for further depth, the NSC needs outside experts at the forefront of science and technology. These experts must, of course, be versed in the strategic and tactical, as well as the technological aspects of weapons systems.

Since 1951, the Presidential Science Advisers have been engaged in the national security area, and have attended NSC meetings when technical considerations were involved.

The Domestic Policy Council (DPC). In monitoring the Administration's domestic goals, the DPC reviews programs in areas such as health, natural resources, transportation, energy or education -- all of which are heavily influenced by S&T. Scientific and technological considerations may set limits on what can be accomplished, or may offer opportunities to reduce costs or increase benefits. In the DPC, these considerations interact with economic, social, legal, and political factors.

The Economic Policy Council (EPC). The EPC coordinates activities concerning domestic and international economic policy. The Assistant would help in defining the economic policy environment needed to strengthen the contribution of S&T to economic growth, and in framing economic and fiscal policies aimed at restoring American industrial leadership.

Other Executive Office Organizations. The President may wish to establish new Executive Office organizations or change existing ones. For example, new organizational and institutional arrangements may be needed to deal with U.S. industrial competitiveness, a major domestic policy issue facing the new Administration. The assistant must play a key role in this area.

> **The Commission recommends that the Assistant for Science and Technology have a strong and formal relationship with the National Security Council, the Domestic Council, the Economic Policy Council and the Office of Management and Budget.**

Supporting Executive Office Oversight.

Many of the activities of the Assistant, in his capacity as Director of the OSTP, involve review and oversight of S&T-related programs. The Assistant, through the OSTP, will need to cooperate with many parts of the Executive Office and with the departments and agencies to oversee programs and policies from an Executive Office perspective.

Office of Management and Budget (OMB). The Assistant's involvement in the budgetary process is particularly sensitive. As Director of OSTP, the Assistant is directed by the Congress to advise the President on S&T budgets and assist the OMB with an annual review and analysis of R&D funding proposals. OMB strongly influences the content, scope and direction of Federal research and development programs, and the organization of the government's S&T activities. The relationship between the Assistant and the OMB leadership must be robust if the Assistant is to be effective.

Program oversight and review. Because of the pervasiveness of S&T in departmental and agency programs, Executive oversight is critical. For example, research and development in atmospheric sciences are of interest to the Department of Commerce, the Department of Interior, the Department of Agriculture, the Department of Defense, the Department of Energy, the Environmental Protection Agency, and the National Science Foundation. At a minimum, information should flow readily among the departments and agencies and the Assistant. Ideally, fully informed oversight can identify undesirable duplication as well as locate gaps and assure that, overall, the research and development policies and programs are being effectively carried out.

One existing mechanism for these purposes is the statutory Federal Coordinating Council for Science, Engineering and Technology (FCCSET), chaired by the Director of OSTP. The members of FCCSET are the top-ranking scientists and engineers in the department and agencies. It operates through specialized panels. Informed observers believe that neither FCCSET nor its predecessor, the Federal Council for Science and Technology, performed the oversight functions adequately. The Assistant will need to explore other approaches to coordination.

The Science and Technology Report.

The OSTP Director is required to submit a "Science and Technology Report and Outlook" to the Congress no later than January 15 of each odd-numbered year. This report, which was intended to provide the Congress with a current statement of the President's policy for maintaining the nation's leadership in S&T, has not been provided regularly by the OSTP.

The biennial Science and Technology Report could serve a useful purpose and be a valuable mechanism for Presidential outreach not only to the Congress, but to the general public. Its preparation, however, is a substantial task requiring significant staff resources.

Testifying Before the Congress.

The Director of OSTP is called on to testify before the Congress, primarily on the OSTP appropriation, but also on substantive matters. There has been a lingering concern that requiring the OSTP Director to testify may conflict with the confidentiality of his advice to the President as a Presidential Assistant. Experience has shown that the Congressional Committees have been sensitive to this issue, and it has not been a significant problem.

V. S&T ORGANIZATION WITHIN THE EXECUTIVE OFFICE

The President must decide how to organize the S&T expertise and advice he needs within the White House staff and Executive Office of the President [3]. There are four organizational considerations:

- the status of the S&T staff Assistant,
- the S&T capabilities within the Executive Office,
- the capacity for in-depth S&T policy analysis, and
- drawing on outside S&T advice.

Although these considerations are treated separately in this report, they are interactive parts of an S&T management system that must involve the non-governmental as well as the governmental sector.

Status of the S&T Staff Assistant

We have recommended the appointment of an Assistant to the President for Science and Technology. The significance and pervasiveness of S&T in Presidential decisionmaking and the increased complexity of technological issues justify this status and the need for direct access to the President. The status of Assistant to the President is also a basic ingredient in the recruitment and effectiveness of an outstanding person to perform this function.

Clearly, the personal attributes of the Assistant are even more important than status and title: the ability to relate S&T to short-term needs as well as broad policy concerns, and personality and adaptability to the style of the President and his senior staff. Most important is the ability to establish and maintain the trust, confidence, and interest of the President.

It is essential that officials inside the government perceive that the Assistant has direct access to the President, is effective and has a close relationship with the White House senior staff. The perception may be as important as the reality. If government officials believe that the President understands the importance of S&T to his policy and decisionmaking and that he relies on his Assistant, their cooperation will be forthcoming. The Assistant's relationship with the President will also be the key factor in recruiting a strong technical staff and a cadre of high caliber consultants.

The Assistant could be accorded Cabinet rank (without portfolio). As a Cabinet member, he would participate in Cabinet meetings on his own initiative and could more appropriately chair meetings involving Cabinet members.

Some have suggested that the Adviser be appointed the Secretary of a new Department of Science and Technology that would incorporate a number of S&T

related agencies [4]. Even if there were ultimately to be a new Department of Science and Technology, there will remain a need for a separate S&T Assistant on the President's staff. The Assistant must be viewed as impartial and solely concerned with the interests of the President. If the Secretary of an operational Department of Science and Technology were also the Assistant to the President for Science and Technology, this could be rightly regarded as a conflict of interest when advising on the programs and priorities of other departments and agencies.

The Commission recommends that the science and technology advisory function not be fragmented and that there be a single senior staff assistant reporting to the President on S&T matters with the title of Assistant to the President for Science and Technology. The merits of Cabinet rank should also be considered.

Strengthening Executive Office S&T Capacity

The National Science and Technology Policy, Organization, and Priorities Act of 1976 (P.L. 94-282), which created the OSTP, charged that office with helping to define and implement national science and technology policy, to

- advise the President of S&T considerations involved in areas of national concern,
- evaluate the scale, quality and effectiveness of the Federal effort in S&T,
- advise the President on S&T considerations with regard to the Federal budgets, and
- assist the President in providing general leadership and coordination of R&D programs of the Federal Government.

Even after 12 years, the Office is a long way from fulfilling that mandate.

Of considerable importance in strengthening OSTP are the four Presidentially appointed Associate Director positions provided for in the OSTP legislation. These posts, mostly vacant through the years, should be filled by highly qualified individuals drawn from different scientific and technical fields. The posts should be used to reinforce the policy functions of the Office and to improve the coupling between OSTP and the various offices and councils in the Executive Office of the President. Serious consideration should be given to joint arrangements whereby one Associate Director would work part-time with the NSC staff. A similar arrangement in the early years of OSTP and its predecessor, the Office of Science and Technology, proved highly constructive in promoting cooperation between the two offices and introduced outside S&T expertise in the work of the NSC staff. Similar joint arrangements with the Office of Management and Budget and other Executive Office agencies should be considered for other Associate Directors.

The coupling problem extends outside of government as well. There are many perplexities about how to relate Federal S&T policies and programs to the private sector. It will be a task of the Assistant to find ways to strengthen and effectuate this coupling.

The performance of the OSTP depends on the size and quality of its full-time professional staff. Over the years, successive Administrations have tended to limit the number of the staff and outside consultants to levels that are unrealistic in relation to OSTP's policy and program responsibilities. The presently authorized staff is fifteen positions. Eleven of these are filled and there are about fifteen others on detail from other agencies. The budget for Fiscal Year 1989 is about $1.7 million.

The Commission recommends that the President strengthen the Office of Science and Technology Policy by appointing outstanding professionals to the four posts of Associate Director. Part-time assignments of Associate Directors to other bodies in the Executive Office, such as the NSC staff, should be explored, as well as arrangements to achieve close coupling with the budgetary and legislative staffs.

The Commission further recommends a substantial strengthening of the professional staff support of the OSTP as an essential step in the invigoration of the S&T advisory function.

S&T Policy Analysis.

For the President to have the best assessments of major policy options involving S&T, the Assistant and OSTP need clear-cut authority and suitable resources for eliciting independent policy-oriented analytical work outside of the Executive Branch. The National Research Council (the operating arm of the National Academies of Science and Engineering and the Institute of Medicine) can provide in-depth analysis of high quality. Additional analytical capabilities are found in scientific societies, universities, other not-for-profit organizations, and established technical consulting firms. In addition, the Congressional support agencies (the Office of Technology Assessment, the Congressional Research Service, the Congressional Budget Office, and the Government Accounting Office) are respected for the quality of their bipartisan reports dealing with matters of S&T.

The Commission recommends that the OSTP be funded for commissioning outside analytical studies in depth.

Drawing on the Outside S&T Community

The range and quality of S&T advice needed by the President cannot be obtained by depending solely on in-house competence. The President can often rely on the departmental and agency staffs, but their expertise is usually narrowly focussed and their advice is often colored by mission commitments and bureaucratic self-interest. Furthermore, developments at the frontiers of science and technology are diverse and their pace is accelerating. Not only does the President need the advice of individual experts from the scientific and technical community outside the Federal Government, but he also needs a responsive mechanism for securing their collective judgments.

The Commission considered the organizational arrangement of the White House Science Council (WHSC), which was established in 1982 by President Reagan's first Science Adviser. Members of WHSC are appointed by and report to the Adviser, and it is chaired by a council member.

The Commission also considered reliance on *ad hoc* panels.. This approach, which was employed during the Ford and Carter Administrations, can deal usefully with specific questions. Without an overview committee, however, the early warning and agenda setting function is lost and the findings of the panels cannot readily be judged or their broader applicability determined.

Having considered the organizational alternatives, the Commission fully supports the establishment of a Presidentially appointed S&T advisory group that reports to the President through the Assistant for Science and Technology, who serves as its chairman. Many informed participants in the contemporary S&T scene strongly support this approach.

The advisory group would both respond to the President's requests and initiate studies in areas of national significance, consistent with the wishes of the President. It would critically review S&T proposals, act as a sounding board for the Assistant, and add authority to the Assistant's judgments on S&T issues. The Advisory group's deliberations could also help resolve differences of views among the Executive Departments and Agencies. Presidential appointment will be important to recruit outstanding members of the group and, particularly, to elicit the time commitment necessary if the group is to be effective and useful.

The Commission recommends that the President establish an outside group of dedicated senior science and technology advisors appointed by the President, headed by and reporting to the President through the Assistant for Science and Technology. Members of the group should agree to devote a substantial portion of their time to its work. *Ad hoc* panels should be convened for in-depth examinations of particular subjects.

ENDNOTES

[1] The members of the Commission and Advisory Council are listed on the inside front cover.

[2] See statement establishing the Commission by Dr. David A. Hamburg, President, Carnegie Corporation of New York, in Appendix A.

[3] The current apparatus has evolved gradually over the past three decades; some highlights of its organizational history are summarized in Appendix C.

[4] Suggestions for a Department of Science and Technology have arisen from time to time over many decades. A Departmental reorganization of this magnitude would likely entail very extensive analysis, discussion, and legislative attention. This question has not been studied by the Commission.

APPENDICES

STATEMENT ESTABLISHING COMMISSION

Statement by Dr. David A. Hamburg, President,
Carnegie Corporation of New York

Issues Underlying Formation of the Commission

Since 1940 the pace of advance in basic scientific knowledge -- of the structure of matter and life, of the nature of the universe, of the human environment and even self-knowledge -- has accelerated dramatically. These scientific advances have provided an unprecedented basis for technological innovation, especially in the context of political and economic freedom. Such technological innovations have pervasive, worldwide effects beyond prior experience.

Science and technology bear upon war and peace, health and disease, the economy and society, resources and the environment -- indeed the entire human future. The international economy, for example, is increasingly driven by developments in science and technology: witness telecommunications, biotechnology, computers, and the technical upgrading of established industries. No reminder is needed of the immense impact on societies of weapons development and distribution. The issues involve not only the existence of the new hardware but the uses of hardware.

These trends are intrinsically worldwide in scope. Many problems historically considered as internal might better be viewed as domestic aspects of international problems. Moreover, the opportunities and problems arising out of modern science and technology cut across traditional disciplines and sectors of society. Thus, institutional innovations are needed that can transcend traditional barriers -- disciplinary, sectoral, and geopolitical.

Clearly, wise policy and administrative decision making in each sphere of life depend on access to the best available knowledge and advice in the various fields of science and technology. Sound advice requires analysis, and analysis requires a broad base of research and development on which informed decisions can be made. Decision makers, moreover, need an understanding of major facets of the scientific enterprise itself.

The rapid and pervasive transformations resulting from science and technology call for strengthening the institutional capability for objective analysis of critical issues based on a broad foundation of knowledge and experience. The government of the United States is in an extraordinary position to stimulate and support such inquiries at a level far beyond what it has done up to now. In addition, the states, the "laboratories of democracy," need better means for dealing with the ongoing and potential applications of research and development.

The Federal Government and the states have an obligation to see that the country exploits the opportunities and avoids the dangers inherent in modern science and technology. This involves, among other desiderata, an understanding of the impact of science and technology on both governmental and nongovernmental tasks. It requires the establishment of a continuing, dependable capability for analyzing policy questions in ways that take adequate account of their scientific and technological aspects.

Science and technology policy itself should strive to meet the following goals: 1) maintaining excellence, technical competence, and efficiency in the conduct of research and development; 2) broadening participation in scientific activity as well as in the benefits of applied science; 3) shaping the uses of science toward widely shared ends -- for example, the relief of human suffering, economic well-being, equitable distribution of resources, and the peaceful resolution of disputes; and 4) encouraging scientists to participate analytically in the uses of science -- at the interfaces of fact and value -- neither avoiding nor dominating the processes by which the social uses of science are decided.

The nation needs several mechanisms, both governmental and nongovernmental, for analyzing thoroughly and objectively the various options relating to two broad questions: What can science do for society, and how can society keep the scientific enterprise healthy? The capacity for providing the best possible analysis and advice on long-term issues of great national importance must not only be built into government operations themselves; the nation must institute ways of capitalizing on the capability of its diverse nongovernmental institutions to gain and provide such analysis and advice. This orientation emphasizes ways in which science and technology can help to identify the early warning signals of emerging problems and spot neglected or new opportunities for improving national and international well-being.

The Challenge

Thoughtful policymakers have increasingly felt the need for intelligible and credible syntheses of research related to important public policy questions. What is the factual basis drawn from many sources that can provide the underpinning for constructive options in the future? Pertinent information is widely scattered among government agencies and quasi-governmental or nongovernmental institutions. Moreover, it is very difficult for the nonexpert and sometimes even for the expert to assess the credibility of assertions on emotionally charged issues. In the current process of world transformation, studies are needed to tackle vital and complex issues analytically rather than polemically. This means having access to a wide range of high-quality information, analyses, and options. Jumping to conclusions, or using a heavy ideological filter, can easily lead to major mistakes, missed opportunities, or even disasters.

The central question for thoughtful consideration is how the various branches of government can take careful account of science and technology in policy formulation and implementation affecting all aspects of modern society. What are the mechanisms government now has that are useful for analysis in each major area of responsibility? Which mechanisms should be strengthened or created? How can the various branches of government be organized to improve their operations through the use of modern scientific advances?

Further, how can the government stimulate and utilize the full range of science and technology in the scholarly community both in and out of government, taking into account ethical considerations pertinent to each problem area? Questions about government's role in specific facets of the scientific enterprise include:

l) Science policy: What are the conditions under which science flourishes in the United States?

2) Technology policy: What are the conditions under which the science base can fruitfully be drawn upon for useful technological innovation?

3) Technology assessment policy: What institutional mechanisms and analytical methods are needed for ongoing assessment of major technologies with respect to the humane, constructive uses of technology?

4) Science education policy: How can the nation achieve a technically literate citizenry and a skilled work force at all levels of human endeavor as well as prepare first-rate scientists and science-based professionals?

Carnegie Commission On Science, Technology, And Government

In November 1987, the Corporation convened a consultative group of experienced scientists and administrators to examine the issues concerning the central role of government in using and stimulating scientific and technological advances for humane purposes. There was general consensus that problems in this regard exist in the executive, legislative, judicial, and regulatory branches and that in-depth analysis of these problems is needed if enduring improvements are to be made. There was additional agreement that an effective approach to the problem would be a commission that would work for about three years with a small high-quality staff. The commission would be intersectoral in nature and include distinguished former government officials, eminent scientists, and private sector leaders.

It was further recommended that the commission should consider the entire range of the sciences -- physical, biological, behavioral, and social -- as well as the technologies based on them. The main emphasis should be on mechanisms by which the government can systematically assess the ways in which science can contribute to the general well-being of the nation, with special emphasis on the most serious social problems. Mechanisms for sustaining the health of the scientific enterprise should also be considered.

The recommendations of the consultative group were adopted at the Corporation's February 17 meeting of the board of trustees, and the new Carnegie Commission on Science, Technology, and Government was duly created with an initial $500,000 grant.

In addition to eminent scientists, the Commission includes former government officials who have served at high levels in all branches of the government. Leaders from nongovernmental sectors of American society are also included.

Co-chairs of the Commission are Joshua Lederberg, president of The Rockefeller University, and William T. Golden, president of the New York Academy of Sciences and editor of *Science and Technology Advice to the President, Congress, and Judiciary* (Pergamon Press, 1988).

Executive director and member of the Carnegie Commission is David Z. Robinson, most recently executive vice president and treasurer of the Corporation. Dr. Robinson, who received a Ph.D. in physics from Harvard University, is a former research physicist and was a staff member of the President's Science Advisory Committee. He will continue to serve Carnegie Corporation as senior counselor to the president.

The Commission will organize studies, issue interim reports, and make its final recommendations in about three years, with a two-year follow-up period. It will be assisted by an advisory council.

LIST OF PRESIDENTIAL S&T APPOINTMENTS

EXECUTIVE OFFICE OF THE PRESIDENT

President's Foreign Intelligence Advisory Board

Office of Management and Budget
- Associate Director for Human Resources
- Associate Director for National Security and International Affairs
- Deputy Associate Director, National Security Division
- Associate Director for Natural Resources, Energy and Science

National Security Council
- Special Assistant for Arms Control
- Special Assistant for Defense Policy
- Special Assistant for Intelligence Programs
- Special Assistant for International Programs/Technology Affairs

Central Intelligence Agency
- Deputy Director for Intelligence
- Deputy Director for Science and Technology

Council on Environmental Quality
- 3 Members

Office of Science and Technology Policy
- 4 Associate Directors

CABINET DEPARTMENTS

Department of Agriculture
- Assistant Secretary for Science and Education

Department of Commerce
- Undersecretary for Oceans and Atmosphere (NOAA)
- Assistant Secretary for Telecommunications (NTIA)
- Assistant Secretary and Commissioner of Patents and Trademarks
- Director, National Institute of Standards and Technology (NIST)
- Assistant Secretary for Productivity, Technology and Innovation

Department of Defense

Assistant Secretary, Production and Logistics
Assistant Secretary, Command and Control (C3I)
Director, Defense Research and Engineering
Assistant Secretary, Health Affairs

Department of Education

Assistant Secretary, Educational Research and Improvement

Department of Energy

Deputy Secretary
Undersecretary
Assistant Secretary, Conservation and Renewable Energy
Assistant Secretary, Defense Programs
Assistant Secretary, Environment, Safety and Health
Assistant Secretary, Fossil Energy
Assistant Secretary, International Affairs and Energy Emergencies
Assistant Secretary, Nuclear Energy

Department of Health and Human Services

Assistant Secretary for Health
Surgeon General, Public Health Service
Director, National Institutes of Health

Department of Housing and Urban Development

Assistant Secretary for Policy Development and Research

Department of the Interior

Science Advisor
Assistant Secretary, Land and Minerals Management
Assistant Secretary, Water and Science

Department of Labor

Assistant Secretary, Mine Safety and Health

Department of State

Undersecretary for Security Assistance, Science and Technology
Special Advisor, Arms Control Matters
Ambassador-at-Large, Non-Proliferation and Nuclear Energy Affairs
Office of Negotiations on Nuclear and Space Arms with USSR
Assistant Secretary, Bureau of Oceans and Environmental/Scientific Affairs

Department of Transportation

Assistant Secretary, Policy and International Affairs
Administrator, Federal Aviation Administration

AGENCIES

Arms Control and Disarmament Agency
Director

Consumer Product Safety Commission
5 Commissioners

Environmental Protection Agency
Administrator
Deputy Administrator
Assistant Administrator for Research and Development

National Aeronautics and Space Administration
Administrator
Deputy Administrator

National Science Foundation
Director
Deputy Director
National Science Board

Nuclear Regulatory Commission
5 Commissioners

HISTORY OF THE PRESIDENT'S S&T ORGANIZATION

All Presidents since Truman have recognized the value of tapping a broad range of S&T knowledge from outside the government. President Truman appointed a science adviser who served in the Office of Defense Mobilization and also had direct access to him, though this access was seldom used. The systematic use by the President of S&T advice began in 1957 with Sputnik. President Eisenhower brought James Killian into the White House as his Adviser, with the title of Special Assistant to the President, and elevated the Science Advisory Committee from the Office of Defense Mobilization so that it reported directly to him.

President Eisenhower sought advice in responding to Sputnik and to the competing proposals of the military services. The Adviser also was involved in the organization of NASA and the establishment of the Office of the Director of Defense Research and Engineering and the Advanced Research Projects Agency in the Department of Defense. There were important questions regarding technical intelligence, and the possibilities for a nuclear test ban. Members of the President's Science Advisory Committee were mobilized for these tasks, and many of them spent substantial time in Washington. The Adviser also helped establish high-level S&T posts in the departments and agencies. Toward the end of the Eisenhower Administration, the Adviser and PSAC added to their work the concern for the advancement of science.

President Kennedy kept the same bipartisan PSAC mechanism with some systematic rotation of its members. In order to institutionalize the advisory function, he established the Office of Science and Technology (OST) in the Executive Office of the President. The title of Director of OST (confirmed by the Senate) was added to that of Special Assistant to the President and Chairman of the President's Science Advisory Committee. The Adviser's staff was transferred from the White House to OST. The Adviser's portfolio broadened to include health, civilian science and the environment.

The Adviser's role continued under President Johnson and through President Nixon's first term. During this period, the Adviser and PSAC were deeply involved in national security issues particularly as related to the Vietnam war, arms control and the treaty to eliminate biological weapons.

After the election in 1972, President Nixon abolished both OST and PSAC. These actions appeared to derive from two principal concerns. One was that former PSAC members had opposed the President's position in testifying before the Congress on anti-ballistic missile defense. The other was the disclosure of the existence of a PSAC panel report questioning the development of a supersonic transport, a project that had been strongly supported by the President. Perhaps the most important underlying factor was the cumulative effect of years of strain between the White House and the academic community over the Vietnam war, and the perception by the White House staff that PSAC was part of that community.

President Nixon added the duties of Science Adviser to those of the Director of the National Science Foundation. His advisory work concentrated on energy R&D, problems in industrial R&D, agricultural research, and academic-industrial cooperation.

President Ford asked Vice-President Rockefeller to recommend appropriate organization for S&T advice to the President. The OST function was resurrected in the Executive Office by an Act of Congress in 1976 in the form of the Office of Science and Technology Policy. President Ford reestablished the Adviser's position in the White House and created the President's Committee on Science and Technology, authorized by the legislation, which worked particularly on energy and individual research issues.

Presidents Carter and Reagan named their science advisers after their inauguration. Although the President's Committee was not continued, President Carter's Adviser appointed *ad hoc* panels of non-government scientists and engineers to advise him on certain issues. He dealt with questions such as the MX missile, the test ban, space policy and air quality standards.

In 1982, President Reagan's Adviser established a White House Science Council of outside consultants that reported to the Adviser, rather than to the President. During this Administration, the Adviser has dealt with matters such as the strengthening basic research, the National Aerospace Plane, Stealth technology, the Strategic Defense Initiative, and international S&T agreements.

Summary of a Plan

for

Conducting a Needs, Alternatives and Feasibility Study

on

Improving the Research and Analysis Capability

of

The Office of Science and Technology Policy
The Executive Office of the President

Study Sponsored by

The Carnegie Commission on Science and Technology
10 Waverly Place, New York, New York 10003

Performed by

Professor William G. Wells, Jr.
and Dr. Mary Ellen Mogee
The George Washington University
Washington, D.C.

INTRODUCTION

In April 1988, the Carnegie Corporation of New York established the Carnegie Commission on Science and Technology, co-chaired by Joshua Lederberg, president of The Rockefeller University, and William T. Golden, president of the New York Academy of Sciences. Its major purpose is to assess the processes by which the Federal Government and the States incorporate scientific and technological knowledge into policy and administrative decision making.

The Commission is sponsoring a series of special studies related to its major purpose with respect to the Congress, the Executive Branch and the Judiciary as well as the States. For example, the Commission issued a major report on October 24, 1988, titled, Science & Technology and The President. While the Commission's mandate covers all parts and levels of government, it has given priority attention to how the President gets scientific and technical advice and assistance.

It is in the context of this series of studies that a needs, alternatives and feasibility study is being conducted on improving the research and analysis capability of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. Along with an assessment of the needs, a number of key issues and concerns related to feasibility or workability of various alternatives will be addressed.

While a full needs assessment has not yet been completed, a preliminary review of Congressional oversight and budget hearings as well as discussions with knowledgeable individuals -- including some former presidential science advisors -- suggest there is a sufficient basis to perform this study.

STUDY APPROACH

The "Needs" Question

An early and critically important facet of the study is to examine as fully as possible the "needs" question. This entails a review of the legislative foundations and expectations for OSTP, various appraisals of past OSTP performance bearing on its research and analysis capabilities (internal and external), and various prior suggestions for improving OSTP performance.

Another part of the "needs" question will be an examination of how OSTP's role may have changed over time due to the increasing complexity and expanding range of issues facing the President which involve science and technology. Examples are the urgency of dealing with environmental-energy issues, industrial competitiveness, and the increasing internationality of many issues.

The output of this examination will take the form of a "Statement of Requirements" or "Criteria" related to improving OSTP's research and analysis capability. More specifically, it must be determined what are the features of past and current OSTP operations -- in terms of the quality of information, analysis, advice and decision making -- which may have been absent and need to be added or are in need of improvement. In short, the "criteria" resulting from this examination will be used to analyze the various alternatives noted earlier. Examples of such "criteria" may be as follows:

- Rapid response capability for information and analyses.
- Close interaction between OSTP and other sources of research and analysis support (e.g., the agencies, the National Research Council) which includes familiarity with presidential issues.
- Capability for broadly based analyses which have high credibility.
- Degree of insulation from "fire-fighting" pressures.
- Ability to analyze science and technology-related policies and programs cutting across federal agencies and departments.

Alternatives Examination

A number of alternatives -- as noted earlier -- will be examined in light of the "needs and criteria" analysis. The alternatives fall into four categories:

- Expanding the size and scope of OSTP.
- Expanding/enhancing existing organizational support arrangements within the Federal Government (e.g., the National Science Foundation, the various departments and agencies).
- Expanding/enhancing current non-governmental support capabilities (e.g., the National Research Council -- NAS/NAE/IOM, various non-profit organizations which provide an array of services to government).
- Establishing a dedicated entity which would be external to the Federal Government, initially, but which could eventually become a part of or be funded by the Government -- in whole or in part.

NOTE: An important point to underscore is that the various alternatives should not be considered as mutually exclusive.

Important Concerns Related to Feasibility or Workability

Each of the alternatives identified in the study will, as discussed above, be examined in light of the criteria arising from the "needs" review. An extension of this review will also require consideration of a number of other issues which may not fall clearly in the domain of criteria but which are important to the overall analysis in one way or another.

The following is a listing of such issues or concerns -- along with brief explanations:

- Financial acceptability: there are federal budget increase implications -- albeit modest -- for each of the alternatives except -- at least initially -- for establishing a dedicated entity outside the Federal Government. The acceptability issue in the latter alternative is whether private sources would be willing to support such a capability for several years on an experimental basis.

- Political and Public Acceptability: each of the alternatives must be reviewed in light of potential political support or opposition within the Congress, the Executive Branch and the scientific and engineering communities.

- Relationship Between OSTP and Research and Analysis Arrangements: items included under this heading include such matters as OSTP's governance role relative to the research and analysis supporter, OSTP operating policies and procedures, OSTP degree of exclusiveness, and the security and confidentiality of work and communications performed for OSTP.

- Experiences of Various Research and Analysis Support Organizations: clearly of major relevance will be the experiences of a number of organizations -- inside and outside the Federal Government. For example, there are the federally funded research and development centers; the National Research Council -- NAS/NAE/IOM complex; and, dedicated Congressional entities such as the Office of Technology Assessment, the Congressional Research Service, and the General Accounting Office.

o <u>Legal Issues</u>: in varying degrees, a number of legal issues arise with respect to the various alternatives. These include the application of various federal laws such as the Freedom of Information Act, the Federal Advisory Committee Act, and an increasing number of laws and regulations related to conflict of interest considerations.

o <u>Organizational Structure, Size and Scope</u>: key items to be considered in these areas include the need for new or modified organizational structures, the scope of issues and operations, estimates of "sizing" in terms of personnel numbers and competencies, and the degree of outreach to various communities and organizations.

o <u>Uniqueness or Comparative Advantages</u>: this topic refers to an examination of the alternatives in terms of what are the special comparative advantages possessed in relation to other alternatives.

SUMMARY

<u>The fundamental questions of this study are these:</u>

- Are there needs or requirements for improved research and analysis capabilities for OSTP?

- If so, what are the main alternatives for meeting the needs?

- What are the advantages and disadvantages of the various alternatives in the context of the needs and associated criteria?

- How feasible or workable do the various alternatives seem to be?

THE WHITE HOUSE

WASHINGTON

June 13, 1990

MEMORANDUM FOR ROGER B. PORTER

FROM: D. ALLAN BROMLEY

SUBJECT: CANCER RISKS FROM ELECTROMAGNETIC RADIATION

As you note in your memorandum of April 29 to Governor Sununu there are now two recent reports dealing with the subject of potential carcinogenicity of electromagnetic fields at frequencies associated with electrical power generation and use--one from EPA and one from OTA.

Two of my old colleagues at Yale have been interested in this field for some time and have taken rather strong issue with the OTA report in particular. They are a husband and wife team, Eleanor and Robert Adair. Eleanor is associated with the Pierce Foundation in New Haven and is a physiologist while Bob is the Sterling Professor of Experimental Physics at Yale and for a number of years has been Chairman of the Physics Section of the National Academy of Sciences. In the recent past both have devoted substantial effort to understanding the literature in this field and Eleanor has been involved in some of the relevant experimental work. On the basis of these activities they have concluded that there is no acceptable evidence supporting the alleged linkage between carcinogenesis and exposure to the lower level fields typical at 60 Hertz.

Indeed, in a recent statement from the American Physical Society, it was pointed out that the recent literature demonstrated a most peculiar dose sensitivity where the alleged carcinogenesis appeared to increase as the field strength to which the subject was exposed decreased. Given that rather amazing data, the American Physical Society suggested that an obvious conclusion was that the public should be protected by being subjected to sufficiently intense fields so that the carcinogenesis affect (if real) would be suppressed!

I am enclosing herewith a copy of a paper entitled Are Biological Effects of Weak ELF Fields Possible? that Bob Adair produced for delivery at a recent meeting of the Electromagnetic Energy Policy Alliance (EEPA) recently here in Washington. He intends to publish it in the American Journal of Physics sometime in the near future.

I was particularly taken by Bob's evaluation of the ELF field effects within the framework of what Langmuir at General Electric long ago described as pathological science and for which he gave a set of identification rules (see pages 30-31).

Although I may have missed some key point somewhere along the line, I am afraid that I must class this ELF activity with cold fusion and just to show that this sort of thing is not always unique to the U.S., polywater in the Soviet Union.

Enclosure

cc: Governor Sununu

Are Biological Effects of Weak ELF Fields Possible?

Robert K. Adair
Department of Physics
Yale University

Abstract

The physics of the interaction with tissues, cells, and cell membranes of weak ELF electromagnetic fields is reviewed. Because of the high electrical conductivity of tissues, the coupling of external fields – in air – to tissue is very weak; $\approx 10^{-8}$ at 60 hertz. Thus moderate external fields induce fields in tissue that are very small and much smaller than the fluctuating electrical fields in tissue and cell material that follow from stochastic fluctuations in electron densities. The magnitude of these (Johnson) noise fields is defined thermodynamically to be proportional to $\sqrt{kT\,\Delta\nu}$ where k is Boltzmann's constant, $T \approx 310^{o}K$ is the absolute temperature of living matter, and $\Delta\nu$ is the frequency band width over which the noise is considered. Consequently, weak ELF fields will be masked by noise and have no biological consequence at the cell level unless they act over very narrow frequency bands such as is afforded by resonances.

The class of possible resonances on the cell level is then examined and these resonances are shown to be incompatible with cell characteristics and the thermodynamic requirement that the mean resonance energy be no smaller than $kT = 1/40\ eV = 4.3 \cdot 10^{-21}\ J$. Moreover, if such resonances are to be narrow and have a small width $\delta\nu \approx 1$ hertz, they must persist for a time $\delta t \approx 1/\delta\nu \approx 1$ second which is very much longer than characteristic interaction times in condensed matter of the order of 10^{-11} seconds.

Various esoteric mechanisms (e.g. chaos, soliton effects, Bose-Einstein collective effects) are discussed briefly and shown to fail to impinge on the thermodynamic constraints.

Hence, we conclude that any demonstrated biological effects of weak ELF fields on the cellular level would indicate that such activities operate outside of the scope of conventional physics in much the same way as parapsychology and extrasensory perception.

1 Introduction

As a scientist myself – genus physicist – I have long looked with interest over the shoulder of my wife, Eleanor R. Adair, in the course of her work on the physiology and psychology of thermoregulation; work that brought her to use moderately intense microwaves to induce a thermal load of a special and manageable character on primates such as squirrel monkeys – and Ellie herself.

Since the physics of the interaction of the electromagnetic fields with the biological tissues interested me, as well as Ellie, I began to pay attention to the study of the biological effects of non-ionizing electromagnetic radiation as an interested observer with some qualifications. Last year, I accompanied Ellie to a meeting of the Bioelectromagnetics Society at Tuscon in the category of "significant other". Armed with my spousal badge I attended a session of the society. Later, I expressed my bewilderment to one of the many able people at the meeting at the enthusiasm which part of the audience received some papers that presented very dubious evidence for supposed biological effects of very weak ELF (extra-low-frequency) electromagnetic fields; effects that I considered quite implausible. Commiserating with me, he told me of a meeting of parapsychologists he had attended for curiosity which he said was very similar to the session I had just attended. The existence of ESP effects was taken for granted by speakers and audience who considered that the only questions of interest were the elucidation of the exact character of the phenomena. And the fact that the data as presented were scarcely above noise at best, and that no results were ever confirmed independently in any detail, seemed to bother no one. Of course the parapsychology society elected officers, gave prizes to one another, etc.

I considered the parallel well-taken. I find evidence for biological effects of very weak electromagnetic fields about as convincing as the evidence for telekinesis and very much of the same character. Moreover, it seems that they are almost equally difficult to understand on the basis of our conventional understanding of the physical universe. And of course, I can disprove neither.

Since any discussion of difficulties that arise upon attempts to find a physical basis for biological effects of low intensity, ELF, fields must address experimental claims, a brief summary of some salient features of many of those claims is in order. Here I quote an OTA "background paper[1]" written

[1] I. Nair, M.G. Morgan, and H.K. Florig; U.S. Congress, Office of Technological As-

for the Office of Technological Assessment (OTA) (the emphasis is mine):

"... findings at the cellular level display considerable complexity including *resonant responses or 'windows' in frequency and field strength, complex time dependencies, and dependence on the ambient DC magnetic field created by the earth.* For these reasons ELF fields appear to be an agent to which there is no known analog. ... in the case of fields it is not known what measures or exposures or 'dose' are relevant. ... it may not be safe to assume that if ELF field exposure leads to health risks, exposure to stronger fields or exposure to longer periods is worse than exposure to weaker fields or briefer periods."

Parapsychologists, you have met your match!

For most of us, the accurate description in the OTA report of research in this field is, alone, enough to impeach that research.

But we proceed: In the OTA "background paper" quoted above, there can be found a statement that reads, "studies ... have demonstrated unequivocally that ... the membranes of cells can be sensitive to even fairly weak externally imposed low frequency electromagnetic fields." Sad experience has taught me to check my wallet when any one says, "In all honesty ..." Hence, in the same spirit, I automatically translated "demonstrated unequivocally" to "failed to demonstrate"[2]. Since purported effects on the cellular level, seem to constitute the cornerstone of the set of loose-knit views that suggest to some that we should be wary of very low-level low frequency electromagnetic fields, I will take a little time now to suggest why it is that none of the eminent physicists and biophysicists with whom I have discussed these matters believe in the reality of such effects.

In brief, in any material the charge density fluctuates thermally according to thermodynamic imperatives generating fluctuating electric fields. Since the electric fields in tissues and the cells that make up tissues are much larger than the fields from low level external ELF fields, those external fields cannot be expected to have significant biological effects.

Although there are other sources of biological noise, such as noise generated by muscle excitation and activity, electrokinetic noise from squeezing of electrolyte through tissues, and the 1/f noise from cell membrane activity, that contribute fields as great as 0.1 V/m at frequencies less than 100 hertz, I emphasize the thermal noise inasmuch as the magnitude of that noise stems

sessment, *Biological Effects of Power Frequency Electric & Magnetic Fields – Background Paper*, OTA-BP-E-53 (Washington, DC: U.S. Government Printing Office, May 1989)

[2]I must admit, that having read previously a preliminary paper by the same authors that expressed deep fears of electric alarm clocks, I was a bit prejudiced.

from fundamental thermodynamic bases - not unrelated to the second law of thermodynamics - and must constitute an irrefutable constraint on biology.

In the quantitative features of my discussion of the effects of low frequency, low intensity, electromagnetic fields on biological materials, I will consider especially 60 hertz oscillations, electric field strengths that do not exceed 300 V/m in air and magnetic field strengths no greater than 0.5 gauss (or 50 μT), the strength of the earth's field - the mean electric field at the earth's surface is about 100 V/m. The fields will, in general, be near-fields, and not radiative. Indeed, for the most part, we will not be talking about *radiation* - non-ionizing or otherwise.

2 External Fields and Noise Fields

2.1 Coupling of Tissue and Air for Electric Fields

For environmental concerns, the immediate measure of possible hazard is that field in the air about the tissues. Since the tissues are conducting, a constant external electric field will induce almost no field at all in the tissues. However, an alternating external electric field will induce an alternating electric field in the tissue. But, at low frequencies, ν, the fields E_i in the tissues will be very much smaller than the fields E_0 in the air external to the tissues[3];

$$E_i \approx \frac{3\epsilon_0\omega}{\sigma_t} E_0 \tag{1}$$

where $\omega = 2\pi\nu$ is the angular frequency and $\sigma_t \approx 1$ S/m is the conductance of the electrolyte saturating the tissue. At 60 hertz, $E_i \approx 10^{-8} E_0$. Hence, for fields in the air of 300 V/m, we can expect field strengths in the conducting tissues of about $3 \cdot 10^{-6}$ V/m.

The cell membrane will have a specific resistance of the order of $\rho_{mem} \approx 10^5 \rightarrow 10^7$ ohms and can then be considered as an insulator relative to the tissue electrolyte. In the valid approximation that the resistivity of the membrane material, $\rho_{mem} \gg \rho_t$, the resistivity of the tissue, the field in the membrane, E_{mem} of thickness d of a cell of radius r will be about

$$E_{mem} \approx 1.5\, E_i \frac{r}{d} \tag{2}$$

[3] K.R. Foster and H.P. Schwan, in *CRC Handbook of Biological Effects of Electromagnetic Fields*, p. 27, C. Polk and E. Postow, Eds. (CRC Press, Boca Raton, FL, 1986)

Hence, taking a typical cell radius of $10\,\mu m$ and a membrane thickness of 50 Å, for a field in the tissue electrolyte $E_i = 3 \cdot 10^{-6}$ V/m, induced by an external field of 300 V/m, we can expect a field of $\approx 10^{-2}$ V/m in the insulating membrane.

The fields in different areas of air, tissue, and cell, are shown in Fig. 1 normalized to a field in the air of 300 V/m. Too often, discussion of the effects of weak fields is complicated by misunderstandings concerning the region in which the field is defined. Since we are addressing environmental concerns, the fields labeled "external" in this report are *always* fields in the air about the tissues.

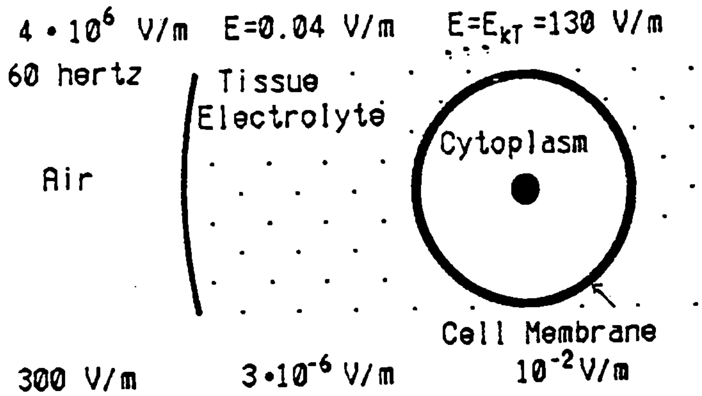

Figure 1: Electric fields in tissues, cell membranes, and cell cytoplasm, induced by ELF external fields in the air outside of the tissue. The fields labeled above describe an externally induced field in the cell membrane that is equal to the Johnson noise, from DC to 100 hertz, measured from the cytoplasm interior to the cell to the electrolyte outside of the cell across the cell membrane. The very large air field so postulated is larger than the dielectric breakdown strength for air of about 10^6 V/m and is then unobtainable in practice. The lower numbers describe the fields induced in the tissue and membrane by an external field of 300 V/m.

Experiments have shown that some fish – especially sharks – do respond to very weak electric fields. These are fields in the water surrounding the fish and are, therefore, strongly coupled to the watery tissue of the fish. In salt water, the fields are more strongly coupled by a factor of $\approx 10^8$ than fields in air to tissue. With special receptors that extend over lengths of tens of centimeters, and which act as low pass filters, the response of sharks to quite small fields – as fields as small as 0.5 μV/m have been detected – does not violate thermal noise limits.

Indeed the size and complexity of the mechanisms required for sharks to sense such fields – and then sense the presence of hidden prey who generate the fields – is a kind of evidence for the general harmlessness of the fields of comparable size, 3-10 μV/m, induced in tissue by external fields of 300 V/m in air. The weak signals are detected by the shark's special receptors – the ampullae of Lorenzini – in as sensitive a manner and processed in as subtle a fashion[4] as the signals of a few photons from a sixth magnitude star are detected by the human eye and processed by the optical system and brain. Even as the ear can detect sound at the thermal agitation level and the nose can detect a very few molecules, the senses have been honed by the imperatives of evolution so that the physical limits of sensitivity are approached.

Then, when as subtle and extensive a system as the shark possesses is required to detect weak fields, it seems evident that those fields are most unlikely to effect biological systems "accidently". And the difference between the strength of fields that will have biological consequences and the weak fields that concern us can reasonably expected to be very great; perhaps like the difference between starlight from a faint star and the midday July sunlight that inflicts sunburn.

2.2 Thermal Electrical Noise

Since the most important fundamental constraint on effects of very weak fields, is the requirement that they not be masked by thermal noise, we present a heuristic explanation of the Johnson-Nyquist noise designed to suggest the salient features of that noise. We proceed by describing thermal noise at a frequency ν in a sample of material by analyzing an imaginary experiment. The sample is inserted as a resistive load R in an LC oscillator circuit such as that shown at the left of Fig. 2 where the circuit elements are chosen such that

$$\nu = \frac{1}{2\pi}\omega \ \ where \ \ \omega = \frac{1}{\sqrt{LC}} \ \ and \ \ \frac{\omega L}{R} = Q \gg 1 \tag{3}$$

From the equipartition theorem the mean energy of the oscillator is $W = kT$ where T is the ambient (absolute) temperature. But as the circuit oscillates it will lose energy (and then cool down below the ambient temperature) as a consequence of the resistance of the sample. The rate of energy

[4]See W.F. Pickard; *IEEE Trans. Biomed. Engr.* **35**, 243 (1988).

loss or loss power P will be

$$P = -\frac{dW}{dt} = \gamma kT \ \ where\ \ \gamma = \frac{1}{RC} = \frac{1}{L/R} \tag{4}$$

Estimating the effective resonance width $\Delta\omega = \omega/Q$

$$P = -\frac{dW}{dt} = \frac{R}{L}\,kT = \frac{R}{\omega L}\,\omega kT = \frac{\omega}{Q}\,kT = \Delta\omega\, kT = 2\pi\Delta\nu\, kT \tag{5}$$

With a more careful evaluation of the effective resonance width,

$$2\pi \rightarrow 4 \ \ and\ \ P = 4\,kT\cdot\Delta\nu \tag{6}$$

The effect of this action will be to transfer heat from the oscillator, which is then cooled below the ambient temperature, to the resistive sample, which is then heated above the ambient temperature. But this is in violation of the *second law.* Hence, if the system is to remain at thermal equilibrium (and we are to avoid violating *the second law*), the sample must generate electrical energy at a rate P at the frequency ν that will be fed back to the oscillator. Hence, the noise power generated thermally by the sample must be equal to P. That power is independent of the magnitude of the resistance of the sample and must hold for any frequency ν even as we could tune the oscillator to different frequencies.

If we write $P = U_{kT}^2/R$ where U_{kT} is the noise voltage across the resistance R, we find the usual formula for that voltage U_{kT} generated by Johnson noise over a frequency interval $\Delta\nu$,

$$\overline{U_{kT}^2} = 4R\,kT\,\Delta\nu \tag{7}$$

Although this noise voltage must follow from thermal fluctuations in the charge density in the sample material, the result – characteristic of thermodynamic results – is independent of detail; in particular of the detailed character of the charge carriers which may be conduction electrons, ions, or bound charges sensibly displaced by thermal buffeting.

Often the noise fields will be of more interest than the noise voltages – which are, however, better defined. Taking the sample as a cube with a side d for convenience, $R = \rho/d$, where ρ is the characteristic resistivity of the material,

$$\overline{U_{kT}^2} = 4\,\frac{\rho}{d}\,kT\,\Delta\nu \ \ and\, taking\ \ E_{kT} = \frac{\sqrt{\overline{U_{kT}^2}}}{d} \tag{8}$$

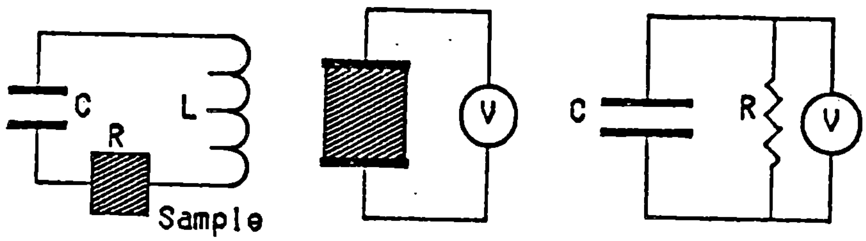

Figure 2: At the left, diagrams showing the oscillator circuit used to define the Johnson noise from a sample of material. At the right is shown a symbolic procedure for the measurement of noise voltage generated by an element of material and the equivalent circuit for that procedure.

average noise voltage U_{kT} can then be expressed as,

$$\overline{U_{kT}^2} = 4RkT\,\Delta\nu = 4\frac{\rho}{d}kT\,\Delta\nu \;\; and \;\; E_{kT} = \frac{\overline{U_{kT}}}{d} \qquad (10)$$

Using the above relations, and taking $\rho = 1\ \Omega \cdot m$ for tissue and a frequency span $\Delta\nu = 100$ hertz – i.e. from DC to 100 hertz – we find that the noise field[5] generated in the electrolyte in a cubical volume the size of a cell, 20 μm on a side, is about 0.015 V/m. This is about 5000 times larger than the field of $\approx 3 \cdot 10^{-6}$ V/m induced in tissue by an external field of 300 V/m. If the volume is 7.5 cm on a side, containing Shylock's portion of one pound of flesh, the mean noise field will be about $6 \cdot 10^{-8}$ V/m. This is about the field generated in tissue by an external field of 6 V/m.

Hence, if external fields as small as 6 V/m – which generate fields in the tissue as large as $6 \cdot 10^{-8}$ V/m – are to have physiological consequences, the physiological mechanisms must act *collectively and coherently* over a pound of tissue.

2.4 Noise Fields in Cell Membranes

Perhaps the most popular "explanation" of the "significant" biological effects of external low-level ELF electromagnetic fields that have been reported, is that these effects derive from the effects of the electric fields on the complex

[5] We note that the thermal noise *potential difference* over 20 μm is but 3 μV. In general, thermal noise voltages between different regions of tissue will be very much less than 1 μV.

properties of the cell membranes. External fields of from 1 to 50 volts per meter have shouldered the most blame and there are claims[6] of effects on cells at field strengths in tissues as small as 10^{-6} volts per meter (which is about that induced in the tissues by fields in air of 100 V/m.) Those fields are presumed to modify such membrane activities as the opening and closing of ion-conducting channels – hence the supposed effect of weak fields on the calcium efflux – and the catalytic activity of membrane-associated enzymes. Of course if externally imposed fields are to have any important effect, those fields at the cell activity sites must not be swamped by the thermal Johnson noise fields.

Certain processes such as the passage of ions through the cell membrane walls may be likely defined by thermodynamic criteria and hence dependent upon the potential difference – which is typically of the order of 50 mV – between the cytoplasm interior to the cell and the electrolyte outside of the cell. For such mechanisms the noise voltage across the membrane from the relatively highly conducting interior cytoplasm to the conducting electrolyte might be more significant than any local noise level[7]. The time average noise level from cytoplasm to electrolyte, across the whole membrane of thickness $d \approx 50$ Å, of a spherical cell of radius $r = 10^{-5}$ m will be;

$$\overline{U_{kT}^2} = 4RkT\,\Delta\nu \quad where \quad R_{mem} = \frac{\rho d}{4\pi r^2} \tag{11}$$

where the resistivity of the membrane material is taken as $\rho_{mem} = 10^6\ \Omega m$. With these values, $R_{mem} = 2.5 \cdot 10^5\ \Omega$. Taking an ELF frequency band of 100 hertz, $U_{kT} \approx 6.5 \cdot 10^{-7}$ V. This thermal noise voltage is probably much smaller than the 1/f noise, possibly associated with the flow of ions through cell membrane orifaces, and smaller by a factor of $\approx 10^{-5}$ than the normal potential difference of 0.05 V across the cell wall[8].

Since this is a measure only of that noise generated at frequencies less than ≈ 100 hertz, if the intrinsic time constants of the biological processes are much smaller then $RC \approx 1/100$ seconds, higher frequency electric fluctuations will contribute to the processes and the effective magnitude of the noise fluctuations will be larger. Conversely, if cell mechanisms exist with

[6]e.g. K.J. McLeod, R.C. Lee, and H.P. Ehrlich, Science 236, 1465 (1987)

[7]The natural potential difference across the membrane will be of the order of 50 mV to be compared with induced and noise voltages across the membrane and the thermal kinetic energy of an ion of $3/2\ kT \approx 37$ meV.

[8]These results are in accord with a more extensive discussion by Frank S. Barnes; *CRC Handbook ibid*, page 121

time constants much longer than 1/100 of a second, the effective frequency band width, and the effective noise, might be substantially smaller.

This noise voltage corresponds to a an electric noise field across a 50 Å thick membrane of $E_{mem} \approx 130$ V/m. Considering the relation, $E_{mem} \approx 1.5\,(r/d)\,E_t$, we see that a field in the tissue of about 0.04 V/m would be necessary to induce such a field in the membrane. In turn, the external field required to produce such a field in tissue and membrane would be about $4 \cdot 10^6$ V/m, hence any effects of a field of 300 V/m would be swamped by noise more than 1000 times larger. This hierarchy of fields is shown in Fig. 1.

It has been argued that the externally induced fields in the cell membrane may affect such biological activities as the catalytic actions by membrane-associated enzymes. If such induced fields are to affect the processes, those fields must be greater than the fields due to thermal fluctuations. Since these kinds of biological activities would appear to be local, determined not by average fields over the whole cell membrane, but by conditions in a small sector of the membrane with a volume no larger than d^3, where $d \approx 50$ Å is the membrane thickness, it would seem that it would be the *local* thermal electric field fluctuations in such small regions that should be compared to the induced fields.

Since the volume in question is quite small, and the effective noise fields over small volumes are greater than for larger volumes, we might expect that the local electric field noise would be much greater than that averaged over the whole membrane. The electrical properties of such a small sector are not necessarily simple but we can *estimate* that thermal noise generated in a small quantity of membrane material proceeding as before by examining the results of a hypothetical measurement of the voltage across the plates of a parallel plate capacitor where an isolated cube of membrane material 50 Å on a side is held between the plates. The time average of the fluctuating noise voltage U_{kT} is again

$$\overline{U_{kT}^2} = 4RkT\,\Delta\nu \quad where\ now\ \ R = \rho_{mem}/d \approx 2 \cdot 10^{11}\,\Omega \qquad (12)$$

If we use the mean resistivity of the membrane material of $\rho = 10^6\ \Omega \cdot m$, for the small sector, which is simplistic, and taking, again, only frequencies less than 100 hertz, the mean noise voltage across this small, isolated, sample will be ≈ 0.02 V. The mean thermal noise electric field over this frequency is then $E_{kT} \approx \overline{U_{kT}}/d \approx 4 \cdot 10^6$ V/m.

Although the specific values of the noise fields must be regarded with reserve, and the effects of such fluctuations on biological processes is not known, we can expect noise fields of this magnitude.

Since the fields E_i in the conducting tissues are magnified in the insulating membranes such that $E_{mem} \approx 1.5(r/d) \cdot E_i$, where $r/d \approx 2 \cdot 10^3$ for cell radii of 10 μm, the field in the tissue must have a value $E_i \approx 1000$ V/m if it is to induce a field in the membrane equal to the local noise field. And in turn, only very large fields - of the order of 10^{11} V/m - in the air external to the conducting tissue can be expected to generate such fields in tissues and membrane[9].

2.5 Electric Field Effects

Although the small values of the ratios of induced to noise electric fields must largely exclude any possibility that those induced fields can induce biological activity in cells, one can reach much the same conclusions using a less broad brush by considering interactions in more detail. To be definite, we consider fields of $E_t = 3 \cdot 10^{-6}$ V/m in tissue, and $E_m = 6 \cdot 10^{-3}$ V/m in membranes 50 Å thick of cells of radius $r = 10^{-5}$ m, induced by external fields of 300 V/m and we compare the energies transferred to the elements to kT.

For membrane or tissue, the energy transferred by the field to an ion - or any singly charged element - in tissue or membrane will not be much larger than $E_t er \approx 10^{-9}\ kT$, where e is the electronic charge. Which is to say neither the kinetic energy nor the direction of motion of a charged element can be sensibly affected by such small fields.

An imposed external field will tend to align electric dipoles so that, even in the face of thermal agitation, there will be a statistical excess of dipoles aligned with the field. That proportion P which are aligned can be taken as $P \approx W/kT$ where W is the alignment energy.

For reasons of symmetry and parity conservation, neither nuclei nor atoms have permanent electric dipole moments but molecules - as more complex structures with less symmetry - may. Taking a characteristic magnitude of such a dipole moment as er where, $r = 1$ Å, the alignment energy will be $W \approx E_m er = 10^{-11}\ kT$. For a macromolecule 100 Å long, the energy will still be only $\approx 10^{-9}\ kT$.

Although for very much larger fields, and for very much higher frequencies, the constantly changing dipole orientations of molecules (such as water)

[9] Since the dielectric strength of air is only about 10^6 V/m, such large fields could not actually be sustained in air.

with large permanent dipole moments result in the transfer of thermal energy to the tissues, the small alignments induced by the small fields we are considering cannot have a significant effect on the individual elements. Collectively, the small macroscopic dipole fields produced by the sum of the microscopic alignments serves only to reduce the effective field in a manner parameterized by the dielectric constant K.

The energy per atom or molecule from the interaction of the fields with induced moments will be very much smaller yet.

2.6 Magnetic Fields

Static Magnetic Fields

Unlike for electric fields, the conductivity of tissues provides little shielding of cells from low frequency magnetic fields. However, the first thing that a crosses a physicist's mind when "magnetic fields" come up, is that magnetism is fundamentally weak. Since the early years of this century, we have known magnetism to be a relativistic consequence of electric phenomena. If Heaven were a democracy instead of an autocracy[10] and the Heavenly Senate established the speed of light as infinite, magnetism would immediately disappear - presumably along with us. Hence, a physicist is immediately doubtful as to the reality of biological effects supposedly generated by weak magnetic fields.

Since magnetic fields exert no forces on stationary charges and act on moving charges only in a direction normal to their motion, static magnetic fields do not add - or subtract - energy from single charges. The magnetic forces do change the direction of motion of charges but that effect - addressed in more detail later - is extremely small compared to effects of thermal fluctuations.

However, charged particles in orbit generate magnetic dipole moments that interact directly with magnetic fields. Unconstrained by symmetries and parity, molecules, atoms, and nuclei possess electric dipole moments μ of the order of magnitude of

$$\mu = g\,\frac{e}{2m}\,\hbar \tag{13}$$

where, for atoms and molecules, $m = m_e$ is the mass of the electron and for nuclei m is the nuclear mass. The alignment energies for a field B are then $B\mu$ and for $B_e = 50\ \mu T$, the earth's field, these energies are of

[10]According to James Branch Cabell in *Jurgen*, it is Hell that is a democracy.

the magnitude of $10^{-7}\ kT$ for atoms and molecules and typically less than $10^{-10}\ kT$ for nuclei. Hence, the net alignment – and the net magnetization of biological material induced by such weak fields is quite small (though significant effects have been observed for very large fields $B \gg 1\,T$.) Such alignments will result in a net (paramagnetic) magnetic moment in a volume of material which in turn will interact with the field defining an energy. For a volume of $10^{-15}\,m^3$, of the whole cell, this energy[11] will only be of the magnitude of kT – more than 12 orders of magnitude less than the thermal energy of the cell! (Some materials are diamagnetic; an external field induces a small moment opposing the field. Arguments similar to those applied to paramagnetic materials apply to the smaller diamagnetic moments.)

The calculation of paramagnetism assumes that the individual molecules or atoms do not act collectively. But for ferromagnetic materials, all of the atomic dipoles line up in macroscopic domains leading to magnetic susceptabilities greater by factors $\approx 10^7$ than for paramagnetic materials. Consequently, an examination of the character of the one piece of biology that is known to follow from the actions of a weak magnetic field – that is the earth's field of about one-half gauss – on ferromagnetic matter in a cell provides illuminating insights into the limitations of biomagnetic effects.

About 15 years ago, Richard Blakemore, than a graduate student studying microbiology at the University of Massachusetts, found anaerobic bacteria (single celled, of course) that, fearing fresh air, fled preferentially downwards guided by the lines of the earth's field. Even as you and I, their guide was a compass of ferromagnetic material, in their case a chain about 2 μm long made up grains of magnetite Fe_3O_4. A simple calculation[12]shows that the alignment energy in the earth's field B_e is $\mu B_e \approx 8\ kT$ where μ is the magnetic moment of the bacterial lodestone. This is enough to ensure efficient alignment of the cell in the earth's field so that the creature swims in the right direction; if the field is made weaker by half, the alignment – and the directed swimming progress – is much impaired.

Hence, with the aid of ferromagnetic materials, a cell can – barely – sense a 500 milligauss (50 μT) field. But with life-or-death not so dependent upon

[11]The number N of aligned molecules in the volume induced by a field B will be $\approx N_0 B\mu/kT$, where N_0 is the number of molecules (taken as water molecules) in the volume. The energy of alignment will then be $W \approx N\mu B$. For the canonical field of 50 μT and $\mu = e\hbar/2m_e$, we find $W \approx kT$.

[12]See Essay 14, by Charles Bean in, *Fundamentals of Physics*, D. Halliday and R. Resnick, 3rd edition, Wiley, New York, 1988; and R.B. Frankel in CRC *Handbook*, p.169, C. Polk and E. Postow, Eds. (CRC Press, Boca Raton, FL 1986)

the reading of magnetic maps for other kinds of life, Fe_3O_4 is found in few other cells. And without the crafting of such compasses, we cannot expect the effects of magnetic fields on cells to compete with thermal fluctuations.

Changing Magnetic Fields

Since life evolved in the presence of static magnetic fields of the order of a gauss or 100 μT, the absence of biological effects of static fields should not be surprising. But Mr. Faraday has shown us that changing magnetic fields generate electric fields. Could 60 hertz oscillating magnetic fields produce electric fields of consequence – that is electric fields greater than those generated by thermal noise. Using the integral form of Faraday's law

$$\oint_S \mathbf{E} \cdot d\mathbf{s} = \frac{d(\int_A \mathbf{B} \cdot d\vec{a})}{dt} \qquad (14)$$

where S is the circumference of the cell and A the cross section, we estimate the mean amplitude of the induced electric field around the perimeter of the cell as

$$\overline{E}_B = \frac{B\omega r}{2} \approx 10^{-7}\ V/m \qquad (15)$$

for a 60 hertz oscillating magnetic field of amplitude B = 500 milligauss field acting on a cell of radius 10 μm.

Then how will this induced field compare with thermal noise fields at low frequencies. Here we take fields across the whole cell squeezed to a convenient cube $d \approx 20\ \mu m$ on a side (as in Fig. 2) where the specific resistance is taken as 1 ohm-m leading to a resistance across the cube of $1/d \approx 5 \cdot 10^4$ ohms. Using this value and taking a conservative frequency band, $\Delta\nu = 100$ hertz,

$$\overline{U_{kT}^2} = 4RkT\,\Delta\nu \ \ and\ \ \overline{U_{kT}} \approx 2 \cdot 10^{-7}\,V \qquad (16)$$

and noise field $\overline{E_{kT}} \approx \overline{U_{kT}}/d \approx 0.015$ V/m. The noise fields are greater than than the electric fields induced by the changing magnetic field by a factor of about 10^4. Hence, low frequency, low intensity, magnetic fields cannot induce biological activity through interactions with individual cells.

Since $E_B \propto r$ and $E_{kT} \propto r^{-3/2}$, the induced electric field will be greater than the noise field only for very sections of tissue greater than the size of a cube 1 mm on a side containing $\approx 10^6$ cells.

In the next section on resonances, we address some resonant effects of ELF magnetic fields and show that they cannot have biological consequences either.

3 Resonances

3.1 Narrow Banding; Signal Averaging

In the description of thermal noise which is commonly used, the square of the mean noise voltage is proportional to the frequency band width over which the noise is measured – or relevant. Hence, if the acceptance of the biological system is such that only a narrow band of frequencies initiate the biological effects, the effective noise interference is reduced. Although an effect that is enhanced by a resonance would constitute an expecially effective frequency filter with a width inversely proportional to the effective Q of the resonance, biological actions that act as band-pass filters are also plausible[13]. In particular, those biological activities that have long intrinsic time constants can act as simple, plausible, low pass filters. If an activity requires a time of 0.01 seconds, it is plausible that perturbations that change sign often in that time would have little over-all effect.

The effective width of the pass-band depends not only on the characteristics of the biological system, but of the signal. A signal – e.g. an ELF wave – that lasts a time t must have an intrinsic frequency spread $\Delta\nu \approx 1/t$. Hence if the resonance width $\delta\nu \approx \nu/Q$ is very narrow, $\delta\nu \ll \Delta\nu$, the effective band width will be $\Delta\nu$ determined by the characteristics of the signal rather than of the system. In that case, the effective frequency acceptance will be inversely proportional to $1/t$ and the effective signal-to-noise will be proportional to $\sqrt{t}$. Or if the signal is *averaged* over a long time t_{max}, the signal-to-noise will be much improved. But only if the effective system width is small compared to $1/t_{max}$. Weaver and Astumian[14] suggest averaging times t_{max} of the order of 1000 seconds (or about 20 minutes!). Such a long averaging time could only be relevant if the intrinsic band width of the system were as small as 1/1000 hertz; if the signal were tuned that accurately; and if the time constant of the biological system were longer than 20 minutes. At 60 hertz – assuming a biological process with a $Q \geq 60,000$, exquisitely tuned to 60 ± 0.001 hertz – the signal to noise voltage from a 20 minute exposure would be improved by a factor of $\sqrt{1000} \approx 30$ over a one second exposure and a factor of about 250 over that from a single pulse.

Even with the factor of 250, which assumes an integration time of about

[13] There can be, and are, biological relaxation effects that admit transfer functions that peak at low frequencies – very much as a band pass filter – but these peaks are quite broad.

[14] J.C. Weaver and R.D. Astumian, *Science* 247, 459 (1990)

20 minutes and a resonance width of 0.001 hertz, (centered, *accidently*, at exactly 60 hertz) the field in the membrane of about 0.009 V/m, induced by an external signal field of 300 V/m, would be much smaller than the noise field of about 0.4 V/m.

At the long ELF wave-lengths, the electric field E must couple to a resonance through a dipole interaction. We can make useful estimate of a *maximum* magnitude of such an interaction energy by considering the interaction of the field with the whole cell. The electric dipole moment P per unit volume of cytoplasm will be $P \approx \epsilon_0(K-1) \cdot \mathbf{E}$ where K is the dielectric constant and $K-1 \approx 80$ as for water and the volume $\mathcal{V}$ of the cell 10 μm in diameter. Then the interaction energy will be about

$$\Delta U = \mathbf{E} \cdot \mathbf{P} \approx 80\, E_{mem}^2 \epsilon_0 \mathcal{V} \approx 10^{-9}\, kT \tag{17}$$

Here the membrane field which the cytoplasm sees is $E_{mem} \approx 1.5 E_t\, r/d$ where r is the cell radius, the membrane thickness is $d \approx 50$ Å, and $E_t \approx 3 \cdot 10^{-6}$ V/m is the field in the tissue induced by an external field of 300 V/m. Hence, the energy would appear to be insufficient to excite resonance oscillations of the whole cell – even if the Q is sufficiently large so that the energies of many cycles can be added coherently.

If a resonance is to be manifest, the damping of the resonance must be sufficiently small that it will make at least one cycle without interruption. If the resonance is to be in the ELF range, that cycle will take a very long time in terms of characteristic molecular collision or interaction times. Consequently, the resonance state must have a very small probability of being interrupted if it is to be significant.

We can estimate the characteristic interaction time or energy exchange time for the smallest elements in a solid as roughly $\approx 10^{-11}$ sec. For example this is about the mean-free-time for collision of a water molecule in water that is considered naively as a gas. Then if the resonance is not to be deexcited by an interaction acting as a collision of the second kind in 1/60 of a second, the probability of that deexcitation in an interaction must be of the order of 10^{-9}. So small a deexcitation probability is difficult to reconcile with the large excitation probability required if the resonance is to be excited by a weak, long-wavelength, electric field. If the cell element is as large as the cell membrane or the cell itself, and if the Q is large so as to allow the coherent contributions of many ELF cycles, the constraints are more severe.

Since some data that are claimed to constitute evidence for the biological activity of weak ELF fields suggest that the fields act only over narrow "windows" of frequency, and since any biological resonances that exist will define narrow frequency bands with a reduction of noise in those bands, we discuss the characteristics of a broad set of possible cell resonances.

In those discussions, we will emphasize the constraints imposed by the character of the resonances and we will not take up either the coupling of the resonances to the electromagnetic field or the damping time or Q of the resonances in detail. However, both the character of the interaction and the damping time pose serious problems if weak ELF fields are to excite resonances.

3.2 Cyclotron Resonances

I will begin by discussing a particular model of effects on the cellular level. Not just to demolish the model, but also – since the model was and is taken seriously by many – to suggest something of the naiveté of the true-believers in the field.

There is long-touted "evidence" that calcium ions pass through chick-brain cell walls when the cells are subject to weak 16 hertz electromagnetic fields. The code word is "calcium efflux". Liboff and McLeod then noticed that under a magnetic field the order of (a little weaker, actually) of the earth's field, that the cyclotron resonance frequency[15] of calcium ions was about 16 hertz. Perhaps this cyclotron resonance was, somehow, responsible for the calcium efflux.

This idea was so well received that even journalists took note. Hence, in the course of reading some magazine – I believe it was either the *National Enquirer* or *The New Yorker* – my friend the eminent physicist Jack Sandweiss read about this cyclotron resonance in some pseudoscience report and erupted. The following analysis stems mainly from Jack[16].

Liboff and McLeod[17] suggested that the energy of the ion might well be about 3.5 eV. But such an ion travels with a velocity of about 4100 meters per second or 250 meters in 1/16 of a second – the circumference of a circle

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[15]The cyclotron resonance frequency $\nu = \omega/2\pi$ for a particle of mass m and charge q in a magnetic field B is

$$\omega = \frac{qB}{m} \tag{18}$$

which is independent of the radius of the orbit or the energy of the ion. For a singly charged calcium ion, a field of 0.42 gauss (42 μT) gives a frequency $\nu = 16$ hertz. The earth's field in the United States is about 0.50 gauss or 50 μT.

[16]Jack Sandweiss, *Bioelectromagnetics*, (in press).

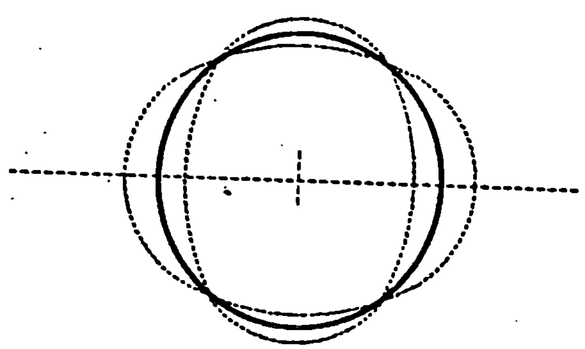
[17]A.R. Liboff and B.R. McLeod; Bioelectromagnetics **9**, 39 (1988), and earlier papers.

Moreover, if the vibration is of consequence to us in our concern over ex-
:ernal effects on cells, the vibrational energy that derives from some coupling with the external environment must be greater than kT, the characteristic thermal energy of any oscillator. Then

$$\frac{1}{2}Mv_{max}^2 = \frac{1}{2}KA^2 \geq kT \quad where \quad v_{max} = \omega A \tag{20}$$

Here, A is the amplitude of the vibration and v_{max} the maximum value of a characteristic velocity while $\omega = \nu \cdot 2\pi$ the angular frequency of vibration. Since the magnitude of the amplitude is limited by the size of the cell, his thermodynamic condition places limits on the magnitude of M and . These limits are severe. Hence the cell cannot entertain low frequency ɪechanical oscillations.

It is interesting to look at a specific oscillation in detail to gain some ppreciation for the strength of the prohibition. To maximize M, we choose hypothetical oscillation of a whole cell where a spherical cell of quiescent adius $r = 5\ \mu m$ vibrates in a quadrupole mode changing from a prolate ɔ an oblate spheroid in the course of a cycle as suggested by Fig. 3. We ıke the density of the cell cytoplasm as 1 gm/cm^3 and set the energy of the ibration at $kT \approx 4.1 \cdot 10^{-21}$ J which in turn sets the amplitude of the 60 rtz oscillation, measured in the direction of the axis, as about 1 μm. This ı substantial oscillation – the radius in the direction of the axis changes about 20%.



ıre 3: The envelope of the amplitude of quadrupole oscillations of a cell or us 5 μm vibrating at a rate of 60 hertz with an energy kT.

In the course of the oscillation, the kinetic energy of motion of the cell erial must be stored in an energy associated with the distortion. Assum- that the cytoplasm is effectively an incompressible liquid, this potential

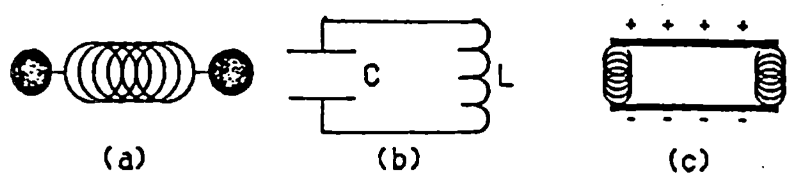


Figure 4: (a) Schematic mechanical resonance; (b) Equivalent LC circuit; (c) Electro-mechanical resonant system.

Such a circuit will be incited thermally such that the mean total energy of kT will oscillate between storage in magnetic and electric fields[5].

We note from Eq. 21 that if the frequency is to be low, the product LC must be large. The capacitance is limited by the size of the cell. The largest capacitance that would seem to be evident is the capacitance between the inner and outer surface of the cell membrane. Taking the thickness of the membrane as 50 Å and the dielectric constant as 2.5, $C_{mem} \approx 6 \cdot 10^{-12}$ f. Then, for a resonant frequency of $\nu = 60$ hertz, the inductance must be $\approx 10^6$ henrys!

It is difficult to design an ideal paradigmatic cell inductance. However, we note that in the absence of ferromagnetic materials in cells and in the absence of a natural source of many current turns, we should expect that the characteristic cell inductance should be of a magnitude such that $L = \mu_0 r \approx 10^{-11}$ H; too small by 17 orders of magnitude! Truly, Nature may be much more clever that we think, but not by 17 orders of magnitude. There can be no 60 hertz LC cell resonances[20].

3.5 Electro-Mechanical Resonances

It is possible to envisage 60 hertz resonances where the potential energy $\geq kT$ is stored capacitatively in electric fields while the kinetic energy $\geq kT$ is manifest in the motion of cell elements as suggested schematically in Fig.

[20] I have heard, however, that an extensive Fourier analysis of a large number of electroencephalagrams of patients in American hospitals showed unmistakable evidence of a 60 hertz component. A similar study of European records showed a 50 hertz component. The difference was ascribed by the investigators to the faster rate of living in the U.S. (This was not from the OTA report previously quoted.)

4c. Again, the storage of kinetic energy requires such large amplitudes of motions of such substantial portions of the cell, that resonances of this kind can be safely excluded along with the purely mechanical resonances[21].

3.6 Nuclear Magnetic Resonances

The interaction of an ambient magnetic field such as the earth's field B_e with the magnetic moment μ of a nucleus (with non-zero spin) generates a torque on the spinning nucleus that induces the nucleus to precess about the direction of the field. Even as the rotating magnetic moment generates an oscillating magnetic field normal to the ambient field, a weak external field normal to the ambient field that oscillates with the precession frequency will generate a precession of the nuclear polarization. The frequency ν of precession is $\nu = B_e\mu/\pi$. For the earth's field this precession frequency for water will be about 2000 hertz; for other nuclei it will be appreciably less. Moreover, the nucleus of an atom is so weakly coupled to the orbital electrons - and then the material environment - that relaxation times can be of the order of 30 seconds and more. So we have a resonance condition at ELF frequencies with a high Q - which is what we have been looking for. Can such resonances have significant biological effects?

No! It seems most unlikely that there can be any biological effect of such resonances. The proportion of the nuclei that will be aligned will be about equal to $B\mu/kT \approx 10^{-10}$ or no more than 1000 per cell! And the energy of those precessing nuclei will be less than 10^{-7} kT. Moreover, as reflected in the large Q, that energy is coupled to the environment of the nucleus very, very, weakly. It is this weak coupling of the nucleus to the atomic structure - and hence to the chemical and biological environment - that makes nuclear magnetic resonance imaging (MRI) such a safe and non-invasive medical procedure though the patient is bathed in magnetic fields of $\approx 4T$, about 100,000 times the earth's field.

[21] There are mechanical processes that lead to current phase lags in biological material that are of an inductive nature. In some circumstances a kind of inertial mass of the ions that carry currents leads to inductive phase lags, and the viscous-like resistance to ion motion also generates a phase lag. Neither of these mechanisms leads to the substantial energy storage requisite for a resonance.

4 Chaos, Solitons, and More

The difficulties in attributing biological effects to very low intensity ELF fields has not passed unnoticed by the true-believers who then ofttimes take hopeful refuge in arcane areas of physics which are not widely understood – by them or others. Consequently, one hears that solutions to the insolvable may be found under such labels as *Chaos*, *Solitons*, *Bose-Einstein Condensations*, *Phase Transitions*, and even *Room Temperature Super-Conductivity*. We comment on some of these excursions.

4.1 Chaos

The very small ratio of imposed field to the noise fields is understood by some who consider, however, that the experimental results – especially concerning the calcium efflux – are nevertheless valid. Some of these true-believers are comforted by Chaos and quote[22] an unfortunately misleading statement dramatizing the chaotic sensitivity to initial conditions of weather; "the consequence of a butterfly fluttering in Beijing is a storm in New York City" to explain their belief that weak electromagnetic fields can affect cell behavior.

The physiology of cells, organs, and organisms may well be chaotic. Chaotic systems are very sensitive – in some sense infinitely sensitive – to initial conditions. Systems, selected from an ensemble, that differ initially by an infinitesimal amount will diverge in a manner such that the initial differences increase – at first – exponentially with time though after a long time the differences between the systems remain within certain bounds. Hence, any minute change in initial conditions must significantly change the final state. Therefore, for chaotic systems, considering the impossibility of obtaining infinitely accurate information on the initial state, it is not possible to predict the character of the final state within broad limits.

However, even as the future of chaotic systems is not calculable, one cannot attribute any specific character of the final state to a specific variation of the initial state. I hope it surprises no one that no storm in New York can be said to be a *consequence* of a fluttering butterfly in Beijing.

But, perhaps I protest too much and, in truth the parallel is well stated: Those who believe that a massacre of butterflies in Beijing will eliminate storms in New York should prudently avoid weak electromagnetic fields.

[22] C.F. Blackman et al., *Bioelectromagnetics*, **10**, 115 (1989); earlier papers by this group are cited here.

4.2 Solitons

The erratic character of the results of experiments that purported to demonstrate biological effects of low level ELF fields suggested to those who believed in the reality of such effects that the known non-linear characteristics of membranes might play some unusual role. Effects that seemed to show up at low intensities (and at specific frequencies - and at particular levels of ambient static magnetic fields), vanished at higher intensities (and at different frequencies and different magnetic fields). It was attractive to consider that non-linearities of membrane functions might lead to such anomalies.

Dynamic systems such that deviations from equilibrium are proportional to the magnitude of a perturbation (a *linear* response), will oscillate in a harmonic fashion under broad conditions and sustain harmonic wave motions. In a corresponding fashion, certain classes of non-linear systems where the deviations from equilibrium might fall off with an increasing perturbation, admit a special single wave-like pulse form, the soliton[23]. While solitons have interesting properties including a kind of longevity resistant to attenuation by the medium through which it passes, the generation of solitons is not immune to the equipartition theorem and weak ELF fields will not produce solitons more effectively than much stronger thermal noise fields.

At any rate, non-linear effects - and solitons - are generally important in systems where the perturbation is very *strong;* e.g. large water waves, very large amplitude vibrations in crystals, and the *strong* interactions of elementary particles.

4.3 Bose-Einstein Condensations

We have pointed out that the local noise at cell membrane sites where biological activity is presumed to take place, is very large. However, if the activity is a collective consequence of effects over larger domains, such as the whole cell membrane[7], the electric field fluctuations are much reduced by a kind of averaging process. If that activity can be understood as a consequence of collective actions of even larger sectors (very much larger), the thermal noise will be reduced even farther admitting, perhaps, the possibility of effects of weak ELF fields.

Such collective activity is known to follow under certain conditions as a consequence of the quantum mechanical description of systems of identical

[23]The simplest membrane non-linearity, which differentiates between the flow of ions into or out of the cell, would not seem to lead to soliton creation.

bosons, fundamental systems each with integral spin in units of $\hbar$. (Such systems are said to follow Bose-Einstein statistics.) In particular, the properties of liquid helium follow from zero spin and Bose-statistics of the helium atom and the BCS (Bardeen-Cooper-Schrieffer) description of superconductivity is a consequence of the Bose-statistics of electron pairs bound - or associated - by phonon interactions. In all cases, the effects occur when the system is condensed and thermodynamically cold - the quantum energy gaps are large compared to kT. But kT is large at $37^o C$ and the fields in the tissue are very, very small. Hence, no plausible application of these concepts has been made to warm biological systems and the prospects that such mechanisms can act collectively over the very large regions necessary, if the thermal noise is to be adequately suppressed, seems most improbable.

5 The Experimental Record

5.1 Problems with ELF Research

Although research into the biological effects of very low intensity ELF electromagnetic fields is connected to researches into the manifest biological effects of higher intensity and higher frequency fields, there are sufficiently substantial differences between these two classes of inquiries to mandate separate consideration.

As for parapsychology, there is no accepted theoretical framework for the biological effects of very low intensity ELF fields and there are no positive experimental results that are accepted by a consensus of those who study the subject[24]. Hence, at the least, those experiments that purport to establish biological effects are difficult and have not been verified to everyone's satisfaction. And the lack of a theoretical framework means that it is most difficult to disprove the hypothesis that weak ELF fields have biological consequences. Indeed, that hypothesis is probably intrinsically non-falsifiable - just as the precepts of parapsychology cannot be disproved. Even as no positive experimental result exists that has not been doubted by many, without a theoretical framework, no experiment can be envisioned that could have a result that would disprove the possibility of biological effects.

[24] The lack of such a consensus concerning *any* piece of experimental evidence for biological effects of weak ELF fields (as for evidence supporting parapsychology) is a fact - easily documented - not to be confused with opinions held variously to the effect that that the evidence and logic is obvious and there *should* be a consensus.

All of this has important consequences on the character of research in the field. Competent scientists who do not believe in biological effects do not work in the field since they do not expect positive results from any inquiry they might mount and find no value in negative results. Hence, for the most part, only those who believe in the possibility of positive results attempt relevant measurements.

Also, a Gresham's law operates on those who do choose to conduct experiments on the biological effects of weak ELF fields. With no theoretical framework, *any* positive result is considered interesting. And since the experiments tend to be complex and systematically "dirty", only those who control their systematic effects with great care and skill will fail to find false positives that can be interpreted as evidence of real effects. The more careless the experimenters the more exciting the results. However, attempts to refute careless work is uneconomical; an erroneous "effect" reported in a casual study that took a few weeks to carry out, can require years of effort to negate. And since the experiments are complex and no theoretical framework exists, the results are nearly unfalsifiable in effect, hence the carefully conducted, major, efforts never completely overwrite the casually conducted experiments that result in weak positives. Those who cannot repeat the results can be considered to have failed to reproduce some essential – and little understood – step correctly.

Moreover, positive results – albeit shoddy – are rewarded. They are publishable and eligible for new or renewed funding support. Conversely, it is notoriously difficult to publish negative results – albeit from work meticulously conducted – that cannot disprove a hypothesis and by-and-large the funding agencies are not interested in supporting work that is so unproductive.

In summary, a general and uncritical infusion of research moneys will only increase the already large set of marginally positive, badly considered, results. Just as increased support of ESP research (or astrology) will lead to more and more marginal claims.

5.2 Windows – and Calcium Efflux

Though we consider that we have shown that it is very, very, difficult to understand how low intensity ELF fields can affect biological processes, can we *prove* that such effects are absolutely forbidden by accepted physical principles? I would distrust any scientist who answered "yes" to such a question unequivocally. And there is an old vitalistic tradition to the effect that there may be special biological laws that do not fall within our description of the physical universe. Such eminent physicists as Schroedinger, Elsasser, and Wigner have found that question – at least – of interest. Hence, we must look at the experimental record but with more reserve, and with more caution, that we need give to more conventional results. If an observer reports that he has seen an apple fall down from a tree to lie on the ground, we are not likely to question him too closely considering the conditions of his observation. But if he tells us that the apple "fell" upwards to finally disappear in the clouds overhead, we must be excused it we review that report more critically. Therefore we consider that we have reason to judge those experiments that conclude that weak ELF fields show biological effects at the cell level – and seem to us to violate thermodynamic imperatives – with a critical skepticism.

Among the many experiments that reported such effects, experiments on the "Modulation of ion flows" holds first place on the OTA list of four "responses demonstrated in laboratory studies using animal cells". Moreover, the authors of that report clearly indicate that they consider that the results from this set of studies comprise the most convincing evidence for biological activity at the cell level of low level ELF. The evidence from the other three 'responses' is seen to be inferior. Two paragraphs from the OTA cheerleader squad serves to describe the experiments and indict players, cheerleaders, and all. The emphases are mine.

"Unusual behavior of calcium efflux ... from cell membranes in brain tissue in vitro was the first *clear, reproducible* effect of ELF fields observed in biological tissue. Bawin and Adey[25] took the two halves of the brain of freshly killed chicks ... [and] exposed one half to an ELF field keeping the other half unexposed ... They then compared the calcium efflux from the two halves and found the efflux was *decreased* in the exposed, compared to the unexposed half. This [effect] ... was noted to have frequency and amplitude 'windows' around 6 and 16 hertz and at [5 V/m] in air."

"In independent ... experiments, Blackman and coworkers[19] also observed a change in calcium efflux, although it was an *increase* rather than a decrease, with a complex pattern of several 'windows'. The frequency ranges they examined were 1-30 hertz and 45-105 hertz, and the intensity range, 1 to 35 V/m."

Fields in the air from 1 to 100 V/m correspond to fields in the tissue of from 10^{-6} to 10^{-8} V/m and corresponding membrane fields of from $1.5 \cdot 10^{-3}$

[25]S.M Bawin and W.R. Adey, *Proc. Nat. Acad. Sci.* **73**, 1999 (1976)

to $1.5 \cdot 10^{-5}$ V/m. If the whole cell membrane acts collectively, the effective noise field will still be about 130 V/m, at least 10,000 times the membrane fields induced by the experimentally induced electric fields. If we consider, implicitly, broader models, we can compare the fields induced in the tissue at large with the noise fields generated in those tissues. Here we note that if external fields of the order of 10 V/m are to effect physiological processes, the fields must act collectively over a pound of flesh as the mean thermal noise generated in that amount of tissue will be about equal to the field in the tissue induced by a field of 10 V/m in the air about the tissue.

These equipartition arguments against the possibility of any biological effectiveness of such weak fields are a formidable barrier to any belief in the experimental claims. Chick brain cell, chick brain, and the chick itself all have masses too small to entertain even collective actions over the whole from weak ELF fields that would not be masked by the noise generated in the tissues themselves.

The OTA report describes the results: "Instead of showing an effect that increased or decreased with increasing or decreasing frequency or intensity, the effect appeared at certain values of frequency and intensity but not at others." And, "Further experiments by Blackman et al., showed that the position of frequency and amplitude windows was influenced by the strength and relative orientation of any static magnetic field superimposed on the AC field."

In short, in sets of measurements, Blackman sometimes found increases in efflux while Adey sometimes found decreases. And, aside from the difference in the sign of the effect, the aberrations found by the two groups occurred at different frequencies and power levels[26].

It is, perhaps, the intensity windows that are reported that makes it most difficult to accept the calcium efflux results. It is an almost firm rule of the behavior of systems that, above an action threshold, the response to a perturbing signal increases at least linearly with the incremental signal. This linear increase will generally be terminated only when the signal is so large that it can no longer be considered a perturbation. Since it is very difficult to consider that the small signals in question are sufficiently large to have any effect at all, the view that they can be so large as to dampen out a response is even more troubling[27]. Moreover, the windows seem almost

[26]There were also at least three attempts, - at major laboratories - to replicate the Adey or Blackman results that found no ELF dependent calcium efflux at all. Private communication; John Bergeron, Eleanor Adair, Kenneth Foster

[27]Intensity windows are not impossible; C.H. Durney, C.K. Rushforth, and A.A. Ander-

maliciously defined (by man or by Nature) to thwart simple verification of the effects. If such windows did not exist, the verification of the effects of small fields would be simple as the experiment could be conducted with much larger fields to elicit a much larger and more easily detected response.

Considering the difficulties with these data, a Jacques Derrida deconstruction of the OTA phrase "clear and reproducible" is in order. The *clarity* is reserved for the faithful, and it is not the effect but the claim of an effect that is *reproducible* – since the effect itself, as observed by different groups, differs in sign, and in the frequency and amplitude of the inciting ELF field.

5.3 Pathological Science

In the euphorically non-critical OTA review previously cited, the authors state: "Among the responses demonstrated in laboratory studies using animal cells and tissues are:

- modulation of ion flows;
- interference with DNA synthesis and RNA transcription;
- interaction with the response of normal cells to various agents and biochemicals such as hormones, neurotransmitters, and growth factors;
- interaction with the biokinetics of cancer cells."

I restate the OTA comment on these demonstrated effects, "[These] findings at the cellular level display considerable complexity including resonant responses (or, 'windows') in frequency and field strength, complex time dependencies, and dependence on the earth's magnetic field."

Almost 40 years ago, Irving Langmuir gave a fascinating talk at the General Electric Knolls Atomic Power Laboratory on the subject of "pathological science". The talk was recorded and an edited version was printed in *Physics Today* recently[28]. Among the subjects Langmuir discussed were the N-rays of Blondlot, the Mitogenetic rays of Gurwitsch, the Allison effect, Joseph Rhine and ESP, and flying saucers. He would have loved cold fusion.

From his analysis of these disasters, he distilled a set of rules to be used to identify pathological science.

son; *Bioelectromagnetics* **9**, 315 (1988), have constructed an ingenious system of cyclotron – and betatron – ion dynamics that would seem to display both intensity and frequency windows but they emphasise that their model cannot describe biological effects.

[28]Physics Today, 42-10, (1989) p. 36.

Symptoms of Pathological Science

(1) The maximum effect that is observed is produced by a causative effect of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.

(2) There are claims of great accuracy.

(3) Fantastic theories contrary to experience are suggested.

(4) Criticisms are met by *ad hoc* excuses thought up on the spur of the moment.

(5) The ratio of supporters to critics rises up to somewhere near 50% and then falls gradually to oblivion.

I grade the biological effects of weak ELF fields A^+ on (1), only B on (2) which is directed more to physics than biology, but A on (3) and A^- for (4), and I would guess that the ratio of supporters (5) is near 50% now – and I eagerly await the oblivion.

Acknowledgements

This is an expository paper and I claim nothing original except for errors and infelicities, and for some of the editorializing. In the course of preparation of the paper, I found essential encouragement and information in the course of many, many discussions with Eleanor R. Adair. I owe a great deal to the papers of Herman Schwan and Ken Foster and to their help and criticism. And I want to thank William Pickard, Robert Pound, Charles Bean, Jack Sandweiss, and Richard Setlow for the benefit of conversations and correspondence as well as too many others to name.