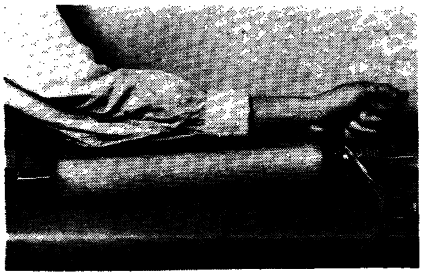

Fig. 12. Mechanical model for the traveling-wave theory, with the skin of the arm substituted for the nerve supply of the basilar membrane. A vibrating piston sets the fluid in the tube in motion, producing waves traveling from the hand to the elbow.

recognized by a shift in the stimulated area. Seemingly the nerve network in the skin inhibits all the sensation to either side of the maximum of the vibration amplitude, thereby producing a sharpening of the stimulated area.

If we compare the three models, we find that the difference limen for "pitch" discrimination below 40 cycles per second is the same because the skin is able to discriminate the roughness of the vibrations as such. But for higher frequencies, displacements of the sensation along the arm, produced either by the resonating model or the traveling-wave model, permit much more accurate frequency discrimination than the telephone-theory model does.

The most surprising outcome of these experiments with models was that pitch discrimination did not deteriorate when the presentation time of the tone was very short. Even when the stimulus was only two cycles, the pitch discrimination for both the resonance model and the traveling-wave model was just as good as it was for a continuous tone of longer duration. Closer examination showed that in both models the place of maximal amplitude was determined during the first two cycles of the onset of a tone. Figure 4 shows that for transients there is very little difference between the vibration patterns of the resonance and traveling-wave theories. In both, waves travel over quite a long section of the vibrating system. The surprising fact is the inhibitory action of the nerve supply, which suppresses all sensation except on a small spot near the maximal amplitude of vibration. In the ear the situation seems to be the same because, there too, two cycles of a tone are enough to enable us to discriminate the pitch of the tone.

Summary

In summing up the current status of the hearing theories, it may be said that each of the vibration patterns of the basilar membrane postulated by the four major theories of hearing can be obtained by varying two elastic properties of the membrane—namely, the coupling between adjacent parts and the absolute value of the elasticity. If these two variables are adjusted to their numerical values in the cochlea of a living animal or a fresh preparation of the human ear, traveling waves are observed along the membrane. These traveling waves have a flat maximum that shifts its location along the membrane with a change of frequency—the place of the maximum determining the pitch. An enlarged dimensional model of the cochlea in which the nerve supply of the sensory organs on the basilar membrane was replaced by the skin of the arm indicates that the inhibitory action in the nervous system can produce quite sharp local sensations, which shift their place with changes in the frequency of the vibrations.

References and Notes

1. This article is based on a lecture given at the meeting of the American Otological Society in Chicago on 10 October 1955. The enlarged model of the cochlea was demonstrated at that meeting. Those present were able to try out the model for themselves and to observe the change in location of the stimulated area on the skin when the driving frequency of the model was changed. This article was prepared under contract N5ori-76 between Harvard University and the Office of Naval Research (project NR142-201, report PNR-179).
2. Articles of mine that are concerned with measurement of the vibration pattern of the human cochlea have appeared in the main in *J. Acoust. Soc. Amer.* from 1947 to the present.
3. S. S. Stevens and H. Davis, *Hearing: Its Psychology and Physiology* (Wiley, New York, 1938); E. G. Wever, *Theory of Hearing* (Wiley, New York, 1949); O. F. Ranke, *Physiologie des Gehörs* (Springer, Berlin, 1953); E. G. Wever and M. Lawrence, *Physiological Acoustics* (Princeton Univ. Press, Princeton, N.J., 1954); and T. C. Ruch, "Audition and the auditory pathways," in Howell's *Textbook of Physiology*, J. F. Fulton, Ed. (Saunders, Philadelphia, ed. 17, 1955), pp. 399–423. For additional titles see S. S. Stevens, J. C. G. Loring, D. Cohen, *Bibliography on Hearing* (Harvard Univ. Press, Cambridge, Mass., 1955).

Secrecy and Scientific Progress

Lloyd V. Berkner

Serious technological secrecy is relatively recent, having emerged sharply as a product of the upsurgence of our technological revolution. There are, of course, a few earlier examples extending throughout history, but they were almost insignificant. But as society generally has become deeply dependent on technological development, so too have the military organizations increased their dependence on science and technology. Initially, at least, it appeared reasonable that the military should restrict the exchange of ideas having military implications on the ground that to permit the free flow of information would hand the enemy our developmental achievements "on a platter."

In the modern world, however, all the important areas of science have military implications and, under our present policies, must therefore fall inevitably under the cloak of military secrecy. Not long ago, for instance, a responsible scientist mentioned to me that he had endeavored to arrange a scientific conference on fundamental high-temperature physics. He found that this was impossible, however, because all the important recent advances were "classified information." At the same time, Marguerite Higgins has reported in the New York *Herald Tribune* for 6 February 1956, "An Indian engineer told me, for example, that Soviet development of heat-resistant materials was far more advanced than anything he had seen in the West." A great many such examples can be cited. Since more and more of our scientific activity is coming within the purview of secrecy, the need for appraisal of the effects of secrecy on our scientific stature and progress, and therefore on our national security, becomes of increasing importance. It

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Dr. Berkner is president of Associated Universities, Inc.

This article is based on his statement to the Government Information Subcommittee of the Committee on Government Operations, House of Representatives, on 7 Mar. 1956.

seems highly probable that a little technological secrecy, like a little poison, may be a good thing, but too much can destroy us. Therefore, it is important to understand just where the balance lies.

A famous psychologist at the University of Michigan once pointed out to me that creative thinking is the reassociation of old ideas in new ways. The really significant new concepts of science are often, if not always, the result of association of widely diverse facts and ideas that may not hitherto have seemed remotely connected. Such ideas as the laws of mechanics and the concepts of space and time derived from astronomy, together with the work of Planck on high-temperature radiation, led Einstein to postulate the equivalence of mass and energy. On this concept is based the development of nuclear energy. Yet today, any intelligent military organization, operating under the present security rules, would certainly classify the equivalent of Planck's work so that it would be denied to a potential Einstein.

In the same way, it is necessary to understand how the benefits of science to our nation will quickly be extinguished by widespread technological secrecy. In suppressing seemingly isolated scientific bits of information of direct military value, we prevent, at the same time, the germination of scientific ideas of much greater scientific, social, and military significance. The great concepts generated from a free and virile science and injected into our industrial complex can provide far greater security through technological supremacy than we could ever hope to achieve through the classification of technological information.

Beginnings of Secrecy

The application of serious secrecy to military technology seems to have coincided with the discovery of radar about 1930. During the ensuing decade, the results were not impressive. In the case of radar, secrecy seriously delayed its development, and neither technical nor tactical progress was very appreciable. As a consequence, although it was technically and demonstrably adequate to have done this relatively simple job, radar failed to prevent Pearl Harbor (a tactical failure born of military ignorance that was imposed by secrecy, for the clear warning of radar was ignored). Had we made known our radar protection of Pearl Harbor, there is at least a reasonable doubt that the Japanese would have attempted a surprise. In any event, our own commanders certainly would not have been ignorant of the powerful tools at their command, and the outcome might well have been very different.

Moreover, the development of airborne-radar applications awaited the war, for at its beginning we had no antisubmarine radar, no night fighters, no means for extensive sea search. The absence of such weapons is directly attributable to the technological ignorance and delays that resulted from secrecy. Had airborne radar been developed and advertized openly, the consequent great progress in these developments might have so weakened the German confidence in their submarine supremacy, or in their capabilities for strategic air attack, that the war might not have occurred. In any event, our shipping losses after its beginning would certainly have been less than the tragic millions of tons.

More recently, the establishment of our northern air defenses was delayed by at least 1, and more probably 2 years by technological secrecy. In fact, the security of information was so good that even the chairman of the Joint Chiefs of Staff did not learn, until after his retirement, that the main underlying technological problems had been solved more than 2 years earlier.

Is there anything in this history to lend confidence in the security that is provided by technological secrecy as contrasted to the security that is provided by progress?

We must understand clearly that, in applying technological secrecy on an ever-growing scale after 1930, we had no previous experience on which to rely, for it arose from a situation new to society and to armies. We did not then understand that technological secrecy is quite a different matter from the secrecy of tactics and battle order, of communication codes, of intelligence, and of intentions. Since that time, our experience with technological secrecy has grown, and it is now time to revise our policies in the light of the consequences that can be read with ever-increasing clarity.

Effect of Present Security Procedures

The maintenance of the widespread secrecy of technological information makes necessary the employment of procedures and regulations for the security of such information. Under these procedures, the scientist cannot avoid becoming the almost unique target, for he is the source of much of the information that is to be protected. It is his creative thought that produces the need for technological secrecy. Yet the application of our present security procedures conditions the scientist to avoid contact with any idea that may lead to military application. Why should this be true? The reasons seem clear.

1) If the scientist knows no "secrets," he cannot be involved in security questions. Scientists are no different from anyone else in desiring to protect their reputations. Once they are involved in secret matters, their reputations may be destroyed by any person who makes irresponsible charges. Because many people accept the cliché, "Where there's smoke, there's fire," subsequent clearance does little to undo the damage.

2) Clearance is not a permanent status, and a scientist's reputation is constantly susceptible to multiple jeopardy. Having once been admitted to secret information or having even originated it, the scientist knows that he may be destroyed by a subsequent change of policy or by other irrelevant circumstances that may result in suspension of that clearance. During each clearance review, his entire life comes under scrutiny, and any act or indiscretion that may have had no relevance to security at the time may arise to damn him. The threat of a review of his security clearance can be used to discourage his exploration of possible alternatives for the correction of national weaknesses—if these alternatives happen not to coincide with current policy.

3) In the process of reassociating ideas in new ways, the scientist must acquire from many sources the ideas to be associated. The development of a new concept does not occur in a flash, but is the consequence of hard thinking and long discussions with scientists of other views and of varied experience. Yet, if the emergent idea is of subsequent military importance and is later classified, the scientist may become involved in security procedures because of the earlier discussions of his own ideas that were an essential precedent to generating the new concept in his own brain.

4) If a scientist has been engaged in scientific leadership in the national interest, he is inevitably involved in extensive security questioning relating to his colleagues, to the views of his colleagues, to his estimate of their intent, and to their statements and actions at informal scientific conferences. He must act as witness at security hearings or render sworn statements concerning events long since past. He may unwittingly and quite improperly involve another through some misinterpretation of his meaning or error in his recollection. The application of security procedures becomes a harassment to all involved.

5) If a scientist expresses a strong view on some technological matter that may be contrary to the application of technology to current or to subsequent policy, he is open to the accusation of taking this view with the intent of deliberate subversion. If, as a consequence of study, he finds a serious deficiency in our military position and advocates a course of action to correct that deficiency, he

may be accused of conspiracy against the existing, though inadequate, policy. Moreover, secrecy prevents him from stating the essential technical grounds on which his view is based. Therefore, in the simple process of doing his job for his country well, he is open to damaging criticism against which he is permitted to produce little defense.

6) In a system of widespread technological secrecy, the scientist finds it increasingly difficult to sort out from the tremendous multiplicity of facts those that are secret and those that are open. He may not even know that a scientific fact, obvious to him, is classified as secret somewhere in the system. Consequently, his knowledge of secrets tends to restrict productive scientific discussions far beyond the necessity of the security system. But, if he errs, he must be certain to err on the side of safety. Therefore, the freedom of discussion, on which the maintenance of his professional competence depends and from which really great scientific progress emerges, is severely hampered.

7) The clearance procedure itself is complicated by a requirement that numbers of detailed forms be submitted to a multiplicity of agencies at frequent intervals. Clearance involves intolerable red tape and loss of much time and energy.

The situations that I cite are not hypothetical; each one can be documented by specific cases. The point is that the security process strongly conditions the scientist *not* to do those very things that most need to be done to preserve the technological supremacy of our country. Under these circumstances, we have lost the spontaneous will and opportunity for men to contribute to our strength when they possess special knowledge and the vision to see how it can be applied. Responsible men recognize the conditioning and will not consciously permit it to stand in the way of their duty and responsibility to their country and to the ideals that it represents. But repeated applications of these security procedures make the average scientist feel a little like the dog in the psychological experiment who is kicked every time the bell is rung. Presently, he runs quite unconsciously when the bell of "military security" is rung, without waiting for the kick. There is a limit to the frustrations experienced by the really creative scientist beyond which his creativeness is destroyed irrespective of his willingness to serve. The scientist who originates and works with secrets—and this includes most of them—is subjected to pressures and influences that are not experienced by other Americans. The scientists are not asking for preferential treatment, but for a relief from distracting pressures that are unknown to most other Americans—a relief that is imperative if scientists are to keep the United States abreast of scientific progress.

I do not say these things in criticism of the security system. As long as we have widespread technological secrecy as a national policy, I doubt that these defects in its application can be avoided; nor does their existence excuse any violation of either the spirit or letter of security procedures. I point out these defects in order that we may understand the consequences of technological secrecy. The proper balance between security derived from secrecy of technological information and security derived from progress must be understood clearly.

There is one other point that we cannot escape. An important concept in science is no less important to our national security because it is produced by one who cannot be "cleared" by the arbitrary application of security procedures. We must not forget that Hitler and Mussolini abrogated their right to the atomic bomb when they indulged in the doubtful extravagance of driving a few leading scientists from their shores because they could not be cleared according to Nazi or Fascist lights. Scientific greatness always rises from diversity of thought, never from conformity. Since the security procedures that support technological secrecy inevitably put a premium on conformity, they tend to prevent our nation's realization of the very greatness that we seek. For technological secrecy tends to obscure the essential dependence of democracy on diversity of thought and opinion. In the atmosphere of conformity, induced by our present neurosis, the encouragement of the diversity on which our system of free enterprise depends has been sometimes considered a form of subversive activity bearing on a man's security clearance, despite constitutional guarantees. An agile brain that can create great things is almost certain to be nonconformist.

The effect of the clearance procedure goes far beyond the protection of secrets. There is the case of one of our great chemists, a Nobel laureate, who was directing his learning to the synthesis of a suitable blood substitute. If a blood substitute could be found, this man with his superb skill could find it. Because of irresponsible charges from undisclosed sources, the support of his work was cut off by a nonmilitary agency of the Government. No formal charges were made; no hearing was possible since the work was not secret. There was no opportunity to clear these charges. Here we must ask ourselves, is it better for our security that the work of this man be cut off, or that we have the means of saving thousands of lives on the battlefield (and millions of lives at home should atomic attack ever come)? The lowest levels of personal clearance, such as the Atomic Energy Commission's "P" approval, or files check, and its military equivalents on men who are doing nonsecret work, are the most dangerous devices ever introduced in democracy. For the individual can be and often is blacklisted without recourse or even knowledge of it.

Balance between Secrecy and Free Information

Therefore, technological secrecy tends to put many of our best thinkers behind a wall across which they have no communication with our Government. Moreover, this wall excludes many of the great foreign scientists of our time. Can we afford the policy of banishing or banning great scientists in the face of our present perils? One recalls the remark of Lagrange to Delambre the day after the execution of Lavoisier: "Only a moment to cut off that head and a hundred years may not give us another like it." Therefore, it is imperative that we find the best balance of technological secrecy as weighed against free information—a balance designed to give us optimum strength. I will try to enumerate the factors involved.

1) The system of technological secrecy must not involve large undertakings. In a democratic system, it is absolutely impossible to cloak large undertakings in secrecy. Their very existence can be seen and discloses their main purposes. Large numbers of men—janitors, factory workers, engineers, scientists, and managers—know essential details. As I once remarked elsewhere, "It is like trying to hide an elephant under a paper hat." Since leaks inevitably occur for reasons beyond anyone's control, the enemy is informed, but our own scientists on the whole are not. Consequently, enemy progress on such undertakings is very possibly greater than our own. Penetration of a large scale project by a determined enemy is impossible to prevent by any known method except perhaps an Iron Curtain around the whole country.

2) The number of secret projects should be sharply limited. A widespread system with leaks is not rigidly respected. Therefore, the security value of those few projects that should be highly protected is devalued since they are jumbled together with thousands of projects that should never be classified at all. Consequently, the widespread secrecy system defeats the essential security. Real secrecy on a few critically important technological matters should be enforced rigidly and at every step. Only a few small critical projects can be policed with the rigidity that insures real hope of success. Technological secrecy should never be used where there is doubt that

its effectiveness can be complete, and should only be used in defined situations when there is complete confidence that it will be effective.

3) Technological secrecy is lost with the passage of time. Unlike tactical secrets of the battlefield that terminate with the battle, technological secrecy on a weapons project or idea has no natural terminal date. All technological secrets deteriorate with time, and they should be arbitrarily declassified after a year or two so that the technological advantage can continue to accrue from greater progress.

4) Basic scientific and engineering information should not be classified or restricted at all. The information that can be used for military purposes is so vast that it cannot be protected. Attempts to do so stop the flow of information on which progress depends. Here I am reminded of the case of the military scientist who was scheduled to present a paper before an important scientific meeting abroad on a subject that had been declassified. Although the paper was in print and was to appear 30 days later, he received a cable as he was about to read it, forbidding its presentation. The reaction of the high-level scientists abroad was certainly not suited to the enhancement of American scientific prestige. Often American scientists find subjects classified that are common knowledge abroad. Not infrequently, discoveries made under classified projects here are later published as original discoveries by foreign scientists.

5) The number of persons requiring clearance should be very small. This is the very essence of a good secrecy system. Moreover, the remaining bulk of individuals are then free to discuss, exchange, and utilize scientific information completely and without restraint. The regulations necessary to the maintenance of secrecy over large areas of technological information condition the scientist to miss the conception of militarily valuable ideas. Although responsible men resist such conditioning, the resulting frustrations inevitably reduce his creative effectiveness. Moreover, excessive security of information prevents some of the world's most creative men from contributing to our national welfare.

6) The security of progress should be the prime objective. We must not assume that what is good for the Soviet Government is good for us, though even the Soviet leaders sometimes find too much secrecy has disadvantages. I note in the New York *Times* for 27 February 1956 that during the 20th Congress of the Communist party "The attack on undue secrecy in scientific work was launched by Anastas I. Mikoyan, a First Deputy Premier, and carried a step further by Premier Nikolai A. Bulganin who accused many incompetent scholars of using it to conceal their failures."

The great forte of our democracy is the ability of free enterprise to adopt the best of all alternatives. We should provide freedom of knowledge for these alternatives to develop so that the choice is ours.

7) Widespread security of technological information is inimical to the security of progress. The security of progress provides well-developed weapons and men trained to use them effectively. In the absence of an Iron Curtain, security of information must depend on compartmentalization of knowledge. Very little compartmentalization is needed to destroy scientific progress or to restrict training and limit tactical familiarity with new weapons. Therefore, if we are to have security based on progress, the information to be restricted must be sharply delimited. If, eventually, we should have to fight, we must decide now whether it is to be with effective weapons about which an enemy knows a great deal, or with pieces of paper about which he knows nothing.

8) The secrecy of technological information is incompatible with the public policy function of a democracy. In our elective system, in the absence of public debate, there is no certainty that policy-making officials will possess the competence required for wise decisions or that they will even understand what elements of information are important. Moreover, even assuming the wisdom of policy-making officials, sound policy results from the careful examination of facts by the people of a nation in light of their diverse training and interests. Secrecy prevents the discussion necessary to such examination, and compartmentalization prevents proper evaluation even by trained specialists. The press and other public media are the sources of the background intelligence that most influences our policy-makers and military leaders. No adequate substitute can be found in internal intelligence because information unevaluated by public debate lacks the convincing quality that results from public review.

9) Widespread secrecy of technological information keeps the public ignorant of the adjustments it must make in the face of technological change. Failure to make adjustments to an evolving environment has in the past led to the extinction of a species. Yet the desire to make such adjustments can emerge in the human species only from a sound understanding of the alternatives as they become clear from public debate, or from the ultimate disaster into which society blunders.

10) Widespread technological secrecy with respect to national capabilities may lead the enemy to underestimate our power and encourage him in irresponsible adventures leading to war. There are many examples of this, although none can be proved absolutely, for events never conjoin in the same way in history.

Conclusions

A deep and searching inquiry into the restrictions on technological information is needed to determine where the public interest really lies. Such an inquiry would stand as a major milestone in our development of public policy and our social maturity. It would dispel the blind faith that more and more "secrecy" can somehow save us. It would define the kinds of technological information that should be kept secret and outline procedures for its selection and protection. It would require the exercise of judgment in balancing all of the factors required by the national interest and security in deciding when information should be classified. It would provide for periodic review of classified information and its quick release when appropriate.

We can no longer assume that restrictions on information that insulate the community from vital technological progress are a good thing. We must be hard-headed when we ask: Just what has secrecy brought us? Does the record show that it has provided protection, or is this just a myth? Just where are we stronger because the enemy has been kept in the dark? Or where are we weaker because he does not know our power? Where, because of lack of official understanding as a result of secrecy, has our government failed to press a technological development that would have strengthened us? To what extent are we failing to meet the great challenges of modern technology because inaction is hidden by the restrictions on technological information? Are we losing significant contributions to our safety and welfare that science could make? What secrets can be kept? How can society meet the social implications of a development if it does not have the chance to understand these implications?

And above all, what effect are these restrictions having on our democratic institutions and on our system of free enterprise? Are we permitting secrecy to cover the rise of systems under the absolute bureaucratic control of government beyond which no regulatory appeal can be made? And finally, the jackpot question: Is it true that with the aid of technological secrecy we are maintaining our lead and forging ahead of the enemy? Or is it possible that because of it we are falling behind?