dent is manageable, it is considered feasible to design the reactor building to be gastight and to contain any gaseous fission products released from the reactor. This general approach is the most promising. (v) In reactors using liquid fuels one can consider continuous removal of the fission products. This is probably practical and economical up to a certain point, beyond which the additional operating costs would become prohibitive. (vi) Construction of a widespread warning system and means for rapid evacution or sheltering of people in the path of the cloud.

These are some of the positive measures that can be taken to minimize the risks. There are other elements that can strongly influence the degree and extent of the hazards associated with a nuclear accident. These elements were all introduced as pessimistic assumptions in my description of the maximum possible accident. The considerations that tend to temper somewhat the harsh effects produced by deliberate compounding of pessimism include these: (i) The wind could carry the cloud over less heavily populated and sensitive areas than those assumed. (ii) The wind could be strong and the atmosphere turbulent. This would rapidly disperse the cloud and dilute its concentration. Although it would allow less time for evacuation, the hazards would extend over a substantially smaller area and the people would be exposed to the maximum radiation over a shorter period. (iii) A considerably smaller fraction of the fission products might be released into the atmosphere at the time of the accident. (iv) There would not necessarily be any fallout or rainout.

As a closing thought I would like to recapture a little of the over-all perspective that is all too easily submerged in a discussion focused on accidents and hazards. An important step in the development of any new process for large-scale industrial use is an understanding of possible abnormal, as well as normal, behavior of the equipment and an appreciation of the consequences in the event of malfunctioning. Only with this basic understanding of the process under all conditions can effective steps be taken to minimize the risks. In every field understanding leads to control. We now believe that we understand reactors. There will, of course, always be some risks, but the past 12 yr of safe activities with many different types of reactors is convincing testimony to our understanding of the technology and encourages us to believe that the problems of the future can be met with equal success.

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Need for Public Understanding of Science

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IT would be difficult, I am sure, to work up a debate in this company* on the question whether the American people ought to have a better understanding of science. No one present would want the negative side of that argument. When it comes to ignorance, we are all likely to sound like Calvin Coolidge's preacher on the subject of sin; we are against it.

We can congratulate ourselves, nonetheless, for our unanimity on this question. Not so long ago there was a respectable body of opinion in science which held that what the people don't know won't hurt them. A little knowledge is a dangerous thing, the argument ran; let the shoemaker stick to his last. Decisions on technical matters, whether in public affairs or in industry, ought to be made by experts qualified to deal with the hard and often complicated facts. The less such questions get embroiled in the misconceptions and prejudices of half-informed laymen, the better for everyone.

Admittedly, something of a case can be made for this point of view. I have not done justice to it as it was argued to me by a distinguished chemist some 15 years ago when I asked for help on an article for the lay public. Perhaps he is present here tonight. Perhaps, to borrow a troublesome metaphor, I should have let sleeping dogs lie!

Since we might have a debate after all, let me dispose of my honorable opponent's position right now.

* This paper is based on a talk given at the southeastern regional meeting of the American Chemical Society in Birmingham, Ala., 21 Oct. 1954.

I will concede the logic of his argument. But I call your attention to his unspoken premise and its essential weakness. This is the notion that an orderly and successful society is one which keeps people in their places. Along with much of our chemistry, this notion is an import from the hierarchical, authoritarian culture of Imperial Germany. It did not serve Germany particularly well, nor did it find hospitable soil in this country.

Since I have exposed the opposition's unspoken premise, it is only proper that I should confess my own. I am committed to the proposition that the wisdom of any government increases in direct ratio with the breadth, depth, and intensity of the public discussion that surrounds it. Democracy is not government by plebiscite. The role of the people does not stop at the ballot box. The health and vitality of a democratic society depends on the participation at all times in its decision-making of citizens who are concerned and who keep themselves informed.

Behind this premise there is another one. The argument in favor of the democratic process does not conclude with proof that republics are inherently wiser and stronger than dictatorships. This is incidental to the attainment, or the approximation, of the principal objective for which men organize democratic governments. That objective is to secure for each citizen the opportunity to realize to the full the promise of his endowment as a man. The better-informed man is thus not merely a better-informed voter; he is above all a better-informed man. In the 18th century tradition, the perfectibility of man represents an end in itself.

Since it is chemistry that brings us together here, we may share a parochial satisfaction in recalling that the Founding Fathers put science high in the syllabus of learning that is to lead on to perfection. Thomas Jefferson equated the increase and the dissemination of scientific knowledge, the laboratory and the press, as the principal vessels of progress:

> While the art of printing is left to us, science can never be retrograde; what is once acquired of real knowledge can never be lost. To preserve the freedom of the human mind then and freedom of the press, every spirit should be ready to devote itself to martyrdom; for as long as we may think as we will, and speak as we think, the condition of man will proceed in improvement.

We are agreed, then, on the need for a wider understanding of science. Let us now attempt an estimate of that need. That is to say, let us see how far short of the ideal the present state of public understanding falls.

From this point, it would be easy to give over the rest of this evening to the misunderstanding of science. There is evidence to paint as dark a picture as the mood requires. Anton J. Carlson, the dean of American physiologists, is a generous man and a friendly critic. Yet he once declared that 20th century man somehow manages to survive in his man-made landscape just as ignorant of science and as haunted by superstition as Peking man in his unspoiled, primeval landscape of 100,000 years ago.

With due respect for the warmth of Carlson's feelings, I do not think we need to take as dim a view as he did. The truth is that dryads, leprechauns, and trolls have long since fled a culture that prizes oil burners, television sets, internal combustion engines, deep freezers, and all the other devices that ease and complicate our existence. These inanimate gadgets, animated only by the mechanics' tools, have generated a powerful antidote to the pathetic fallacy of animism that once populated the universe with the creatures of man's fear and imagination. Almost everybody now has acquiesced in the Copernican revolution and the displacement of our earth and us from the center of the universe. There is general recognition of the idea that the cosmos is a vast impersonal system, ordered by laws of mechanics. The germ theory of disease brings people to their doctors, not to their knees. In our law there is increasing acceptance of the idea of the criminal as a victim of psychological and sociological handicaps, an object for treatment not for vengeance. In the relationships of man to man, our fellow citizens are agreed that all men are members of the human race, and they expect that we will eventually learn to act like members of the same human family.

It is extremely doubtful that we could have found such wide acceptance of the rational and scientific view among the members of any previous generation. If we go back just a little way in history we find the world of reason confined to much narrower quarters by superstition, fear, and old wives' tales. Without doubt, future historians will conclude that it was during our lifetime, in the popularization of the rational outlook upon the world among citizens in all occupations and professions, that science had its greatest impact upon the life of mankind.

The ground still held in men's hearts by fear and superstition is thus narrowed. But on many of the most important questions of life, it seems to remain the decisive ground. Ironically, science itself seems to have fallen heir to much of what remains of the frightened awe formerly accorded to the outer darkness. There is reason enough to be troubled about public ignorance of the scientific and technical considerations that bear so heavily on the social and political issues of the day. But we have cause for more serious concern in the real misunderstanding which prevails in our culture about the nature of science as a human enterprise.

Science still occupies the House of Magic in which it was exhibited at the New York World's Fair in 1939. In the popular view science is first of all our most securely established body of knowledge. It is a rich mine of hard facts that have a tougher consistency and more utility than revelation. How these facts originated and got put together, nobody inquires. The notion that they might go on growing in number is disturbing to a large number of people. They raise the question whether there shouldn't be a law or a moratorium or a breathing spell. Scientists are workers in this House of Magic. They are qualified by special gifts—today, of course, they must also be cleared—for access to technical information. Their job is to make something useful out of the ready-to-hand facts. Science is thus primarily an important step in the immense technological process that makes our country so rich and strong. The suggestion that science has cultural as well as technological implications is downright suspect and heretical, if not worse.

I believe you will agree that this is a fair rendering of the image of science as it is held in the public eye and mirrored in our press. It is something more than a merely popular image. It presents its most alarming aspect as it is accepted among otherwise educated members of our society. It contributes to the antirational, antiscientific mood presently ascendant in our culture. It promotes the almost complete estrangement of arts and letters from the sciences, which explains why our humanists largely miss the insights science now offers into so many of their habitual concerns. It is found even among engineers and scientists, who are all too often ignorant in fields outside their own, and among them it tends to confirm a sterile insularity that shirks the cultural and social responsibilities of their profession.

We can easily see, in principle, that such misunderstanding of science in our society presents serious hazards to both science and society. Let us now go from the general to the particular. By examining an actual instance of the effects of ignorance on public policy, we may take a real measure of the peril that confronts scientists and citizens in our country today. I would like to explore the murky controversy that presently embroils the military policies of our Federal Government.

The age of science dawned in the public consciousness in the apocalyptic summer of 1945. Neither generals nor privates in the ranks, cabinet ministers nor defense plant workers—no one was prepared to comprehend the instant annihilation of two Japanese cities. Here was a discontinuity in the steadily increasing horror of war, an abrupt ascent in man's capacity for destructive action.

The atomic bomb was, of course, a straightforward and logical extension of two generations' work in modern physics. Scientists of all of the nations that had scientific establishments had contributed to this work. But nobody had paid any attention to what the physicists were doing. All of the fundamental knowledge required to fashion not only a fission but a fusion bomb was in the public record before 1940. But nobody except physicists had read the literature.

The openness and completeness of the literature available deserves emphasis. Until the scientists of the Allied Nations imposed their own voluntary blackout late in 1939, there had been no occasion and no effort to conceal this work, even that concerning the unexpected discovery of nuclear fission. The January 1940 issue of *Reviews of Modern Physics* carried a survey article by Louis Turner of Princeton University that rounded up the papers on uranium fission then already in print. His bibliography begins with the first report, in 1934, by Enrico Fermi of his exposure of uranium to bombardment by slow neutrons. At this juncture, Fermi and his associates were looking for the then hypothetical transuranian element 93. They published two more papers that year. Their work stimulated interest in other countries. In 1935 seven papers are cited in the field, in 1936 five papers, in 1937 five more, and in 1938 nine papers. Then came the Hahn-Strassman-Meitner work, which developed the true import of Fermi's original experiment. As an index of the speed of communication within the tiny community of physics, Turner's bibliography showed 104 papers published in the year 1939. The bibliography listed contributions from the laboratories of a dozen nations. Out of a total of 133 papers cited, incidentally, a scant half-dozen bear the names of American authors, none of them dated earlier than 1939.

Turner's review article was reviewed in turn in a chapter on nuclear fission incorporated in a standard college physics textbook written by Ernest Pollard of Yale University published in 1940. With the aim of stimulating student interest, Pollard went beyond the formal presentation of the scholarly journal to speculate on the prospect of nuclear reactors that might generate electrical power or detonate as immensely destructive bombs, that might produce radioactive substances for research and industrial processes or for an appalling new kind of chemical warfare.

At the time of the Fermi-Dunning experiment at the Columbia cyclotron early in 1939, even the metropolitan press carried journalistic accounts that developed the spectacular implications of the work. But, again, nobody was the wiser. It was not only the celebrated man in the street who missed the point, but people who should have known better. That includes chemists, too. I remember that one of your leading journals, at about this time, was featuring a series of fanciful letters from its readers, satirizing the quantum theory. It was essentially a jursidictional dispute. A few physicists had presumed to apply quantum notions to a reinterpretation of the chemical bond. Physics, in truth, seemed to be dealing with a "world that is not only queerer than we imagine, but queerer than we can imagine."

As a direct consequence of this void in communication, the atom made its debut in our culture and in our politics as a military secret. The Atomic Energy Act of 1946 gives a measure of the ignorance, and hence the fear, that has engulfed the whole subject ever since. In its section on secrecy, the act gives atomic secrets a peculiar definition. It declares to be restricted

> . . . *all* data concerning the manufacture or utilization of atomic weapons, the production of fissionable materials or the use of fissionable materials in the production of power, but shall not include any data which the Commission from time to time determines may be published without adversely affecting the common defense and security.

In literal translation, this language means that the existing world literature of modern physics, including the 133 papers published before 1940, is declared to be secret until such time as the Atomic Energy Commission might decide to declassify it. This is not secrecy in the only intelligible meaning of the term. It is statutory tabu. Like the tabu of the Polynesian cultures, it derives its sweeping sanctions from popular ignorance.

Herbert Marks, the first general counsel of the Atomic Energy Commission, observed in an article in the *Yale Law Journal* published in 1948 that the administration of the atom from the outset was walled off from the normal processes of "public scrutiny and protest" that are "the chief protections of society against incompetence, unfairness and corruption in government." Today, 9 years later, the tabu still throws its pall over all the immense questions of policy that are involved in the atomic energy enterprise. Among these, the most immediately decisive for the national security and welfare is the role of atomic weapons in our national defense program.

It is only during the last few months that the public has been given a chance to comprehend the extent to which our armament program is committed to big bombs. The *schrechlichkeit* theory of modern war, which rests upon the long range aerial destruction of civil populations, did not work in World War II. The hydrogen bomb may very well have made it the strategy of choice for World War III. But there has been no adequate public discussion of its soundness as a policy for our country. Certainly the debate on the question has fallen far short of our traditional standards of controversy on questions of such political, ethical, and military magnitude.

There was one brief moment, way back in 1948, when the possibility of an alternative military policy was actually debated in the public record. It was occasioned by interservice rivalry and the Navy's effort to preserve its independence within the unified military establishment. According to our native custom, the issue was the popular one of corruption—the question whether the first contract for intercontinental bombers had been properly negotiated by the Air Force. The transcripts of the Congressional hearings that followed are worth reading today. It is the last time that the public record rehearses the arguments in favor of a balanced military establishment designed to destroy enemy military forces and to take and to hold enemy territory.

I do not pretend to be qualified to make a judgment as to the choice of alternatives here. What seems to me more important and worth careful consideration by all responsible citizens is the fact that the decision was made in secret. It was made by a very few men. In making it, they did not have the advantage of the guidance—nor the disadvantage of the pressures—under which our public officials normally make such decisions. Since this is a procedure diametrically at odds with our custom and tradition, we are fortunate now to have at least part of the story in the public record. It is told in the current best-seller of the Government Printing Office, the 992 pages in small type entitled, *In the Matter of J. Robert Oppenheimer, Transcript of Hearing Before the Personnel Security Board of the United States Atomic Energy Commission.* The H-bomb controversy takes up roughly one-third of the million words. It is worth reading for the lesson in elementary civics which it holds.

Here you will find a story of palace intrigue that affronts the traditions of our self-government. The cast of characters includes scientists, lawyers, businessmen, and politicians—a representative sample of American officialdom. For each of them the immense burden of the decision that must be made is many times multiplied by the fact that it must be done in secret. It is clear from the record that no one is immune to the dread anxiety that his choice, whichever way it goes, may later be regarded as wrong. From the scientists on the General Advisory Committee to the politicians, however, you find an increasing tendency to play it safe, to decide that right will be on the side of the biggest bang. It is at this point, of course, that the public would normally be consulted and the responsibility for the decisions, right or wrong, laid where it belongs.

That was not possible here. Accordingly, what should have been questions of merit become questions of motive. Honorable men are impugned in the record of secret intelligence agencies. There is a poison pen letter. One imagination, made fertile by fear, invented a tale of a secret conspiracy of scientists, with a cabalistic code name, that is worthy of science fiction.

This is clearly not the way government is conducted in America. We may hope that the whole issue, now that the only significant security restraints have been breached by the very publication of the Oppenheimer transcript, will be subjected to public review and reconsideration.

Meanwhile, the obsession with secrecy and the ignorance of science from which it springs have done grave damage to the relationship between science and government and hence to the national security that military security procedures are supposed to protect. Recently, before a Congressional Committee, Vannevar Bush declared that the mutual respect between the scientific community and the military services achieved during World War II has been "almost destroyed and one of the principal reasons is the security system." As a result, he said the U.S. defense against continental air attack has fallen 2 years behind where it should be.

For the long-run good of science and the national welfare, this estrangement of scientists and the military might prove to have some advantages. In the present fiscal year the combined expenditures of the defense establishment and the Atomic Energy Commission, adding up to $1.2 billion, account for fully half of all the funds the nation is expending on research and development. The appropriation for the National Science Foundation in this same fiscal year is a mere $8 million. The contrast between these two figures is a measure of the continuing neglect in our country of the needs of fundamental research, or pure science, as contrasted with our lavish expenditures on applied science.

Before the war basic science got one dollar in every six of the country's annual expenditures on research and development. If we add to the National Science Foundation's outlay the full income available from nonprofit foundations and university endowments and credit a generous portion of industry's research expenditures to the account of basic science, the biggest figure we can arrive at is about $120 million. This means that basic science today is getting not more than one dollar out of every twenty.

We have here a cold statement in dollars of the prevailing misunderstanding of the nature of science as an essential enterprise of our culture. This imbalance in emphasis on applied as against pure science has prevailed now for nearly 15 years, ever since American science was mobilized for World War II. Irreparable harm, in the opinion of many observers, has already been done to our scientific resources. The careers of a disproportionate percentage of a whole generation of younger scientists have been diverted to the narrower ends of applied research. Our high schools and colleges, with the offspring of the wartime baby boom on the verge of flooding their classrooms, see their science teachers going off to work as technicians, at higher salaries in industry and government.

By now the crucial relationship between pure and applied science ought to be comprehended by the public and the government. The story has been told over and over again. Ten years ago the original prospectus for the National Science Foundation declared:

> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science.

It is further a familiar fact that America has made "less than its proportionate contribution to basic science." As Crawford Greenewalt put it,

> We have been fortunate in the past in having available to us the results of basic science from the world at large. This has permitted us to indulge our industrial genius, perhaps without at the same time contributing our fair share to the world's fund of basic knowledge.

It is time, at last, that we took active measures to redress the balance of emphasis on pure and applied science.

The very first of these measures must be to develop a wider understanding of the nature of the scientific enterprise among the citizens of our country. The taxpayer has now succeeded the philanthropist as the principal patron of science. If he is to play his role wisely he must be shown that science is not solely or simply a branch of technology, that mere utility has never provided sufficient motive to inspire the curiosity, the initiative, the imagination, and the persistence that is embodied in all great work. To this point J. Robert Oppenheimer has testified,

> We know how little of the deep new knowledge which has altered the face of the world, which has changed —and increasingly and ever more profoundly must change—man's views of the world, resulted from a quest for practical ends or an interest in exercising the power that knowledge gives. For most of us, in most of those moments when we were most free of corruption, it has been the beauty of the world of nature and the strange and compelling harmony of its order, that has sustained, inspirited, and led us. . . . If the forms in which society provides and exercises its patronage leave these incentives strong and secure, new knowledge will never stop as long as there are men.

This declaration of motive might seem, at first glance, a selfish one– it is as if science should be supported because scientists enjoy it. However, the record shows that the trained human mind set free to choose its own objectives turns invariably to deep and significant enterprises. Warren Weaver expressed it thus:

> The most imaginative and powerful movements in the history of science have arisen not from plan, not from compulsion, but from the spontaneous enthusiasm and curiosity of competent individuals who had the freedom to think about things they considered interesting.

If the public is to find such motives for the support of science, then it, too, must be able to enjoy those fruits of research that are beautiful, significant, and interesting as well as useful. Here, in fact, we enter a much wider area of concern than the annual appropriation for the National Science Foundation. For lack of such participation in the life of science we are witnessing a retreat to authority in many quarters in our culture. Among people who are engaged in science there should be more than a guild member's interest in the fact that the major movements in our arts and letters today are antiscientific in spirit.

There is good reason why our contemporary romantics should turn the wrath of their frustration upon science. In the 400 years since Copernicus the scientific enterprise has brought more than an industrial revolution. It has undermined the ancient absolutes in which men once found the purpose and plan of their existence. Nor has the much-praised utility of science proved an unmixed blessing. Technology has made possible, indeed has necessitated, the organization of superstates, giant cities, and vast industrial enterprises. With the attendant centralization of initiative and authority, the individual becomes the anonymous creature of decisions and compulsions originating he knows not where. It is not hard for 20th century medievalists to show that the serf found more happiness in the security of his bondage than modern man in the insecurity of his liberation.

The demands of the human spirit cannot be denied. If we are to maintain individual freedom in our crowded world and manage civilization democratically, then each man must have conviction in his own worth as an individual and purpose that fulfills the personal miracle of his existence. It is now too late in the history of science for men to satisfy these demands by retreat to authority. It is, in fact, impossible for the human mind in its integrity to deny for long the inescapable conclusions of its capacity to know and think.

The rational method offers no absolutes and no blueprints prepared in advance to tell us what we want to live for. But science does broaden and secure the ground upon which men can make their choice. It has already shown that human life is not fated to be, in the words of Thomas Hobbes, bloody, brutish, and short. In our increasingly complete and connected knowledge of the cosmos we have an ever clearer understanding of ourselves and our place in nature. We see that the perfected man, that ideal of the 18th century Enlightenment, is the ultimate product of the cosmic process as it is known to modern science.

Science thus bears upon the ends as well as the means of the life of man. We have need for a better understanding of science among the members of our society not only that we may use the power which such understanding gives us, but that we may use it well.

Liberty Hyde Bailey

MANY great men have served on the staff of Cornell University, but it is probable that none contributed so much to the university and to the country as did Liberty Hyde Bailey. Professor in the university from 1888 to 1903 and dean of the College of Agriculture from 1903 to 1913, he retired in 1913 to devote the remainder of his life to taxonomic research in the field of botany. He died 25 December 1954.

Bailey was born on a farm in the wilderness of South Haven, Michigan, in 1858, 3 years after the founding of the first agricultural college in the United States at Lansing, Michigan, and 2 years after Senator Morrill presented to the Congress the land-grant act that bears his name. Both of these events were to play a large role in Bailey's career.

The farm in the wilderness was a world in itself. Soap, candles, leather, cloth, food, and fuel were all produced on the farm. Friendly Indians peered through windows of the home to see what the white man ate and how he lived. Bailey witnessed the transition of the farm from a self-sufficient unit to the highly specialized and mechanized farm of today. During this period he contributed greatly to making the farm a better way of life—and to a better means of living.

As a young boy he began to marvel at the wonders of nature. At the age of 10 he was collecting plants, insects, and rocks and creating museums in his home or in the barn. At the age of 14 he was grafting scions of superior quality to fruit stock of inferior quality for farmers in his neighborhood. With the aid of a neighbor he began a more systematic study of plants. The land, the fields, the streams, the forest, and books were his primary interests. It was natural, therefore, that he should enroll in the Michigan Agricultural College (now Michigan State College). Here he was influenced by one of the masters in botany and soon was collecting plants for the herbarium and for classroom use.

Following graduation Bailey became a newspaper reporter, but after some months in this field he accepted a position as assistant to Asa Gray, the famous botanist of Harvard University. He became professor of horticulture and landscape art at Michigan State College in 1885. Here he established a department of horticulture, the first in the United States. His reputation as a teacher and scholar and his zeal to bring knowledge to the farmer attracted the attention of Cornell. Bailey was then invited to become professor of general and experimental horticulture and began his work at Cornell in 1888.

His impact on the College of Agriculture was enormous, and he was recognized immediately as an inspiring teacher. He stimulated research and extension teaching. Graduate students came to work under his direction, and a host of his students became leaders in the field of horticulture. Textbooks in horticulture, as well as in other fields of agriculture, were lacking. He began to write books on various phases of horticulture, plant breeding, and evolution, and as an editor he stimulated the preparation of textbooks in the various fields of agriculture. These total more than 100.

Bailey's arrival at Cornell catalyzed the extension movement. He traveled widely in the state, he wrote bulletins on the experimental and research work, and when, in 1894, the state of New York appropriated $15,000 for extension work at Cornell, he initiated experiments to control diseases of the grape by the use of bordeaux mixture. This was pioneer work.

Bailey succeeded Isaac Phillip Roberts as dean and director of the College of Agriculture in 1903. The college was lacking in financial support, and the need for a substantial college of agriculture was clear. Roberts, aided by Bailey and others, had prepared the groundwork and had earned the good will of the farmers. Both emphasized the need for a New York State College of Agriculture supported by the state. Despite active opposition by various educational institutions of the state of New York, legislation was enacted in 1904 to establish the New York State Col-