Science and Trans-Science

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MUCH has been written about the responsibility of the scientist in resolving conflicts which arise from the interaction between science and society. Ordinarily the assumption is made that a particular issue on which scientific knowledge is drawn into the resolution of a political conflict—for example, whether or not to build a supersonic transport (SST) or whether or not to proceed with a trip to the moon—can be neatly divided into two clearly separable elements, one scientific, the other political. Thus the scientist is expected to say whether a trip to the moon is feasible or whether the SST will cause additional skin cancer. The politician, or some other representative of society, is then expected to say whether the society ought to proceed in one direction or another. The scientist and science provide the means; the politician and politics decide the ends.

This view of the role of the scientist, and indeed of science itself, is, of course, oversimplified, in particular because even where there are clear scientific answers to the scientific questions involved in a public issue, ends and means are hardly separable. What is thought to be a political or social end turns out to have numerous repercussions, the analysis of which must fall into the legitimate jurisdiction of the scientist, and each of these repercussions must also be assessed in moral and political terms; or what is thought to be a scientific means has non-scientific implications which also must be assessed in these terms. The relationship between the scientist and the politician is thus far more complicated than the simple model described above.

In this paper I shall be concerned with a somewhat different aspect of the relation between scientific knowledge and decisions on social questions. Many of the issues which arise in the course of the interaction between science or technology and society—*e.g.*, the deleterious side effects of technology, or the attempts to deal with social problems through the procedures of science—hang on the answers to questions which can be asked of science and yet *which cannot be answered by science.* I propose the term *trans-scientific* for these questions since, though they are, epistemologically speaking, questions of fact and can be stated in the language of science, they are unanswerable by science; they transcend science. In so far as public policy involves trans-scientific rather than scientific issues, the role of the scientist in contributing to the promulgation of such policy must be different from his role when the issues can be unambiguously answered by science. It will be my purpose to examine this role of the scientist, and particularly to explore the problems which arise when scientists can offer only trans-scientific answers to questions of public policy in situations in which laymen, politicians, civic leaders, etc., look to scientists to provide scientific answers.

Examples of Trans-Scientific Questions

Biological Effects of Low-Level Radiation Insults: Let us consider the biological effects of low-level radiation insults to the environment, in particular the genetic effects of low levels of radiation on mice. Experiments performed at high radiation levels show that the dose required to double the spontaneous mutation rate in mice is 30 roentgens of X-rays. Thus, if the genetic response to X-radiation is linear, then a dose of 150 millirems would increase the spontaneous mutation rate in mice by $\frac{1}{2}$ per cent. This is a matter of importance to public policy since the various standard-setting bodies had decided that a yearly dose of about 150 millirems (actually 170 millirems) to a suitably chosen segment of the population was acceptable. Now, to determine at the 95 per cent. confidence level by a direct experiment whether 150 millirems will increase the mutation rate by $\frac{1}{2}$ per cent. requires about 8,000,000,000 mice! Of course this number falls if one reduces the confidence level; at 60 per cent. confidence level, the number is 195,000,000. Nevertheless, the number is so staggeringly large that, as a practical matter, the question is unanswerable by direct scientific investigation.[1]

This kind of dilemma is not confined to radiation. No matter what the environmental insult, to measure an effect at extremely low levels usually requires impossibly large protocols. Moreover, no matter how large the experiment, even if *no* effect is observed, one can still only say there is a certain probability that in fact there is no effect. One can never, with any finite experiment, prove that any environmental factor is totally harmless. This elementary point has unfortunately been lost in much of the public discussion of environmental hazards.

The Probability of Extremely Improbable Events: Another trans-scientific question is the probability of extremely unlikely events—for example, a catastrophic reactor accident, or a devastating earthquake which would, say, destroy Hoover Dam and thereby wash out parts of the Imperial Valley of California. Probabilities of such events are sometimes calculated. For example, in the case of a catastrophic reactor accident, one constructs plausible accident trees, each branch of which is triggered by the failure of a particular component. Statistics as to the reliability of each component

[1] To be sure, indirect evidence as to the shape of the dose-response curve for X-rays at very low dosage can be inferred from experiments which measure the relative biological effectiveness of highly ionising radiation and X-rays. Such experiments suggest that the dose-response curve for X-rays at low dosage is quadratic, not linear. However, these experiments are suggestive, not definitive: they still represent extrapolations to very low doses of radiation of the observations taken at high dose.

Of course one may ignore dose-rate effects and increase the dose 30-fold to five rem in order to simulate the possible life dose to a woman during her child-bearing period. Even in this case, at the 95 per cent. level, about 10 million mice would be required. But in any event there are serious difficulties in extrapolating by such data from mice to man.

are often known, since many components of the type under consideration—ion chambers, transistors, control rod bearings—have been tested. But the calculations are obviously suspect, first because the total probability obtained by such estimates is so small—say 10^{-7}/reactor/year—and second because there is no proof that every conceivable mode of failure has been identified. Because the probability is so small, there is no practical possibility of determining this failure rate directly—*i.e.*, by building, let us say, 1,000 reactors, operating them for 10,000 years and tabulating their operating histories.

These two examples illustrate questions which are trans-scientific because, although they could conceivably be answered according to strict scientific canons if enough time and money were spent on them, to do so would be impractical.

Engineering as Trans-Science: Engineering, especially in fields which are developing rapidly, typically involves decisions made on the basis of incomplete data. The engineer works against rigid time schedules and with a well-defined budget. He cannot afford the luxury of examining every question to the degree which scientific rigour would demand. Indeed, "engineering judgement" connotes this ability, as well as necessity, to come to good decisions with whatever scientific data are at hand. Sometimes the crucial data are insufficient for the engineer to proceed: the project then must await further scientific research. Usually, however, the engineer makes do with whatever data he has: he then uses the wisdom called "engineering judgement" as a guide.

The engineer exercises his judgement, on the whole, by being conservative. If he is unsure of the "creep" behaviour of a new alloy, he will ordinarily overdesign his sections so as to withstand the worst conditions he can imagine. The extent of overdesign is largely determined by the engineer's budget: an important incentive for acquiring more data is the desire to avoid costly overdesign.

Uncertainty is in a sense inherent in engineering: unless one is willing to build a full-scale prototype, and test it under the precise conditions which will be encountered in practice, there is always the uncertainty of extrapolating to new and untried circumstances. Where the device being engineered is small, like a jet engine, a full-scale prototype is customarily built: difficulties are worked out either on the prototype or on the early production models. But where the device is huge, like the Aswan Dam, or a 1000-Mw plutonium breeder, or a large bridge, a full-scale prototype is out of the question. Moreover, the service life of such devices may be as long as 100 years: even if a prototype were built, there would be little sense in waiting until weaknesses appeared in the prototype before starting on the next model. Thus in every advancing technology there are inherent elements of scientific uncertainty which as a matter of principle can never be totally resolved. In this sense such technologies are trans-scientific, or at least possess trans-scientific elements. And, indeed, most of the examples I use in the remainder of my discussion are derived from technology, particularly the technology of nuclear reactors.

Trans-Scientific Questions in the Social Sciences: In the social sciences trans-scientific questions arise very frequently. One often hears social scientists classify questions as being " researchable " or " not researchable ". In the former category are, presumably, questions which, at least in the estimate of the social scientist, can be approached with some hope of success. In the latter category are those which cannot.

What makes a question in the social sciences resistant to investigation or trans-scientific? Before the advent of the large computer, I suppose many problems in social science entailed operations which were beyond the capacity of the available manpower. Obviously the computer has changed this. But there remains a very important class of seemingly social and scientific questions which will always be in the realm of trans-science.

I refer to the behaviour of a particular individual. In physics, if we know the initial position and velocity of a specific macroscopic object, and the forces acting upon it, we can predict its trajectory—not the trajectories on the average of many objects like this one, but the trajectory of this particular object. Thus the physical sciences are capable of predicting particular macroscopic events precisely from the laws of nature and from the initial conditions. Moreover, even in quantum physics, we can make precise predictions of the behaviour of a collection of atoms or molecules, and the statistical distribution of the behaviour of the microscopic identities. This enormous proficiency is attributed by Elsasser to the homogeneity of the class of objects of discourse in quantum physics—every hydrogen atom is the same as every other hydrogen atom, and statistical variability can itself be predicted. In contrast, the social sciences deal with classes, the individual members of which display wide variability, as well as being subject to the vagaries of consciousness. Thus the predictions of social sciences are inevitably less reliable than are those of the physical sciences. Moreover, in so far as the social sciences can predict behaviour, it is the behaviour, *on the average*, of large classes. To expect the social sciences to predict individual behaviour, or even individual events, with anything like the precision we expect of the physical sciences is generally to ask too much. Yet public policy often requires estimates of the future behaviour of individuals—for example, in the Cuban crisis President Kennedy had to make some estimate of the behaviour of Premier Khrushchev. Even where many individuals are involved and the event to be predicted is a unique constellation of the action of many people, the proficiency of the social sciences is less than that of the physical sciences. Nor is this simply a matter of the social sciences being " less well developed " than are the physical sciences; it is my impression that there are basic limitations to the predictive powers of the social sciences which derive from the inherent variability and consciousness of the individuals who make up the populations studied by social science. From this point of view, one would argue that much of social science (perhaps with the exception of economics) is indeed trans-science: that its proficiency in *predicting* human behaviour is, and probably always will be, far more limited than is that of the natural sciences.

Axiology of Science as Trans-Science: Still a third class of trans-scientific questions constitutes what I call the axiology of science; these are questions of "scientific value" which include the problem of establishing priorities within science. These are the problems discussed under the name of criteria for scientific choice, as well as the valuation of different styles of science: pure versus applied, general versus particular, spectroscopy versus paradigm-breaking, search versus codification. All of these matters involve "scientific values" or taste rather than scientific truth. In so far as value judgements—that is, ultimate questions of *why* rather than proximate questions of *what*—can never be answered within the same universe of discourse as the one in which the question arose, any resolution of these issues clearly transcends science even though the issues themselves seem to be internal to science.

It should be noted that the examples I have quoted transcend science in three rather different senses. In the first case (low-level insult), science is inadequate simply because to get answers would be impractically expensive. In the second case (social sciences), science is inadequate because the subject-matter is too variable to allow rationalisation according to the strict scientific canons established within the natural sciences. And in the third case (choice in science), science is inadequate simply because the issues themselves involve moral and aesthetic judgements: they deal not with what is true but rather with what is valuable.

Trans-Science and Public Policy

Increasingly, society is required to weigh the benefits of new technology against its risks. In such a balance, both scientific and trans-scientific questions must be asked by those who have the responsibility for the decisions and those who concern themselves with the decisions. The strictly scientific issues—whether, say, a rocket engine with enough thrust to support a manned moon shot can be built—can in principle be settled by the usual institutional mechanisms of science, such as debate among the experts and critical review by peers. But what about the issues which go beyond science, on which the scientist has opinions which, however, do not carry the same weight as do his opinions where these are based on rigorous scientific evidence? These issues are dealt with by two institutional mechanisms: the ordinary political process and adversary procedures.

The political process, in a general sense, establishes priorities: it allocates scarce resources among alternative uses where there is no market place and where there is no objective or agreed norm or standard to govern the allocation. The resources to be allocated may be tangible and specific, as when a decision is made to go to the moon; or they may be much more diffuse and pervasive, as when a national commitment is made to improve the position of minorities. In either case, the resources are allocated and the priorities established by the interplay of competing political views and powers: those who want to build the SST exert what political power they have—the capacity to summon votes, to grant favours, to threaten to withdraw support; and this is resisted by those who dislike SSTs, for whatever reason. In such specific allocations of scientific resources, the scholarly discussion of science policy, dealing as it does with matters which are not internal to science, is intended to elevate and illuminate the political discussion, at whatever level this occurs. It seeks to make the contestants in the conflict more aware of the consequences of any decision and of alternatives, to show them what its implications are in terms of other values, to ensure that they weigh the costs of what they seek and that they are aware of the values which are implied in their choices.

In the other more subtle and pervasive working of the political process—the establishment of social priorities—scientific elements are sometimes involved. Thus, to take the case of the position of the black man in the United States, the Supreme Court invoked a " scientific " doctrine—that educational deprivation caused psychological damage to the individual—as an important argument for its decision to order desegregation. And in the political processes which have followed this decision, this finding from the sphere of social psychology has never been far from the political debate.

The other institutional mechanism for arriving at decisions is the adversary procedure. Though adversary procedure of a sort is implicit in any confrontation, public or private, I shall reserve the term for those formal, legal or quasi-legal proceedings at which proponents, both scientists and non-scientists, of opposing views are heard before a body or an individual who is empowered to render a decision after having heard the conflicting contentions. For example, before a permit is granted for the construction of a nuclear reactor in the United States, the applicant must receive a licence from a licensing board. The board must find that the reactor can be operated " with reasonable assurance that the health and safety of the public is maintained ".

The hearings before the board have a legal aspect. Those who oppose the granting of a licence, usually because they disagree with the likely answers to the questions about the safety of nuclear reactors, appear as interveners. The procedure pits one adversary against another. The arguments used bear close resemblance to those used in the political process, but they are generally more factual because there is face-to-face confrontation and opportunity for cross-examination; there are certain procedural rules of rhetorical etiquette which inhibit the demagogy and exaggeration common in the political process; the contending parties are also usually better informed than impassioned participants in the political process; and finally, they know that they will be asked specific questions by the board or some quasi-judicial equivalent. Through this confrontation both the trans-scientific and the scientific questions related to the side effects of nuclear reactors are resolved.

The adversary procedure is likely to be used increasingly in modern, liberal societies in their attempts to weigh the benefits and risks of modern technology. Certainly this is the case in the United States. For example, the United States Environmental Protection Agency requires statements regarding "environmental quality" from the promoters of any large technological enterprise which might affect the environment. These statements, if challenged, will undoubtedly lead to lengthy and elaborate adversary proceedings.

It is therefore important to examine the validity of formal adversary procedures for settling technological or semi-technological issues. Professor Harold P. Green has argued that in adversary procedures representatives of the public are usually less well informed than are representatives of the applicant and that, therefore, the former are at a disadvantage. This places a heavy responsibility on the agency before which such adjudicative procedures are held to try to redress any such inequality in the positions of the contending parties. To a great extent this now happens in the United States Atomic Energy Commission's review of nuclear reactors. The regulatory staff of the commission subject every application for a nuclear reactor to a searching and highly informed technical scrutiny: the public adversary procedure is the culmination of a lengthy prior analysis by the staff of the Atomic Energy Commission. Professor Green asserts that the regulatory staff of the commission, at such hearings, join with the applicant against the public interveners.[2] This is hardly the view of many applicants who are often distressed and frustrated by the painstaking and slow course which these reviews require.

Whether the adversary procedure is adequate or not seems to me to depend on whether the question at issue is scientific or trans-scientific. If the question is unambiguously scientific, then the procedures of science rather than the procedures of law are required for arriving at the truth. Where the questions raised cannot be answered from existing scientific knowledge or from research which could be carried out reasonably rapidly and without disproportionate expense, then the answers must be trans-scientific and the adversary procedure seems therefore to be the best alternative. In principle, one exhausts all of the *scientific* elements, one

2 Green, Harold P., "The Risk Benefit Calculus in Nuclear Power Licensing", in Foreman, Harry (ed.), *Nuclear Power and the Public* (Minneapolis: University of Minnesota Press, 1970), p. 131 *ff*.

answers every question which can be answered scientifically before dealing with the trans-scientific residue. Thus, with regard to the public hazard of the SST, the scientific evidence for the connection between increased sunlight and skin cancer seems to me to be unequivocal, and I believe experts agree; the matter can be settled by the usual institutional procedures of science. The effect of nitric oxide exhaust from SST engines on the ozone concentration in the stratosphere has less direct empirical evidence to support it, and therefore is more controversial: this part of the issue contains both scientific and trans-scientific elements and might be illuminated by adversary procedures. Finally, the question of whether or not to go ahead with the SST with the evidence at hand is an issue that involves primarily non-scientific questions—for example, the cost as compared to a wide variety of other competing activities. This must be decided by political processes because ultimately the decision to proceed or to desist is a matter of ethical or aesthetic values. Where there is no consensus on these values, the process of decision must be political.

To one trained in the law, a rather formal and somewhat stylised adversary procedure might seem to be a reasonable institutional arrangement for arriving at truth—whether it be legal, trans-scientific or scientific. But to the scientist, adversary procedures seem inappropriate and alien to his tradition. To be sure, such procedures are useful in establishing the credibility of witnesses—that is, in establishing whether the witness is stating the whole truth and nothing but the truth as he sees it. In science, however, the issue is not a witness's credibility; it is his specific competence—that is, his ability to recognise and know scientific truth—and this is not reliably established by an adversary procedure conducted by lawyers rather than scientists. On the other hand, in trans-science where matters of opinion, not fact, are the issue, credibility is at least as important as competence. One must establish what the limits of scientific fact really are, where science ends and trans-science begins. This often requires the kind of selfless honesty which a scientist or engineer with a position or status to maintain finds hard to exercise. For example, in the acrimonious debate over low-level radiation insult between Professor Gofman and Dr. Tamplin on the one hand, and most of the nuclear scientists on the other, neither side was quite willing to say that the question was simply unresolvable, that this was really a trans-scientific question. Thus the adversary procedure undoubtedly has considerable merit in forcing scientists to be more honest, to say where science ends and trans-science begins, as well as to help weigh the ethical issues which underlie whatever choices the society makes between technological alternatives.

There is yet another possible way to resolve some of the unanswerable questions of public or environmental risk caused by new technology: this is to perfect the technology so as to minimise the risk. We say that there is a possibility (which we cannot quantify) that low-level radiation insult will cause cancer. We can never eliminate these insults entirely—our technology is too necessary for our survival to dismantle it, and it is idle to hope that we shall ever have technology with absolutely no risk.

To be sure, we shall always try, through improved technology, to reduce effluents and other by-products from any device. In some measure this is how the debate over the radioactive emission standards from nuclear reactors is being resolved. The original Atomic Energy Commission regulations permitted doses of up to an average of 170 millirems per year to groups of individuals in the vicinity of a nuclear installation. The controversy over these standards has been resolved by technology: nuclear reactors now can be built that emit only 1/100 or less of the original standards, and the standards are being lowered accordingly. The question of the permissible dose has been moved from the sphere of trans-science towards that of science—*i.e.*, the emissions have now been moved much closer to the point (zero emission) where all scientists can agree by scientific standards that there is no danger.

Even the residual risk, the magnitude of which cannot really be determined by science, can be reduced if science can develop a cure for the untoward biological side effects of the environmental insult. This argument has been put forward by Dr. H. I. Adler of the Oak Ridge National Laboratory, and I believe it deserves serious consideration. Suppose we developed a safe and simple method of immunising against cancer. That this is no longer a fantasy is believed at least by the panel which advised United States Senators Yarborough and Kennedy to launch a new cancer programme. Attitudes towards residual and unavoidable contamination of the environment would certainly be modified if there were some form of immunisation against the side effects which gave rise to concern in the first place.

The possibility of genetic intervention would also help eliminate the issue of residual contamination of the biosphere. At present there are 30 or more enzyme deficiencies, presumably of genetic origin, which can be detected in the amniotic fluid. If science could, by amniotic analysis and therapeutic abortion, reduce the risk of genetic abnormality from whatever cause by a large factor, I should think our attitude toward the trans-scientific question of low-level radiation insult would be significantly affected. In offering this possibility, I realise the grave moral and social issues involved in abortion for whatever reason. To me the moral scale weighs heavily against bringing into the world babies who are predestined to short lives of torture; to others, the balance may come out differently.

The Republic of Trans-Science and the Political Republic

The validity of scientific knowledge is established and maintained through the critical judgement of scientific peers. The whole system is described by Professor Michael Polanyi very aptly as the "republic of science ".[3] To qualify for citizenship in the republic of science—*i.e.*, to be accepted as a scientist—one's scientific credentials must be acceptable. Only those with proper credentials, as evidenced by past achievement in science, are allowed to participate in the government of science: only scientists are listened to in the mutual criticism which keeps science valid. What survives this criticism or, as Professor Harvey Brooks puts it, what has value in the " intellectual market place " is incorporated in the corpus of science; all else is rejected.[4]

The citizens of the republic of science—that is, the scientists—are an elite within the larger society. Only scientists participate in the internal government of the republic of science, and the degree of participation of a scientist is determined by his standing as a scientist. Where science and politics meet, however, issues can no longer be settled by scientists alone. The public, either directly or through articulate scientific pamphleteers who speak out as keepers of what they regard as the public interest, often engages in the debate. The issues affect everyone, not just the scientists, and therefore everyone, in some sense, has a right to be heard. A biologist with no credentials in quantum electrodynamics would never think of attending a scientific meeting on that subject: not only would he be unable to understand it, his own scientific work would be untouched by it. By contrast, citizens of the most diverse scientific or educational qualification now participate in debate on repositories for radioactive wastes in salt mines, the dangers of pesticides or the decision to build an SST. The obvious point is contained in the saying that he whose shoe pinches can tell something to the shoemaker.

The " republic of trans-science " (if one can identify something so diffuse as a republic) has elements of the political republic on the one hand, and the republic of science on the other. Its character must therefore reflect to a great extent the political structure of the society in which it operates. In the United States, where the political tradition is strongly democratic and there is relatively little tradition of deference to authority, the debates on trans-scientific issues are particularly noisy. By contrast, in Western Europe, whatever debate occurs on such matters is more subdued, less open. In the Soviet Union, whatever debate occurs on these matters is practically inaudible in public.

What are the advantages and disadvantages of conducting the trans-scientific debate in a completely open manner as is done in the United States? The disadvantages are clear, particularly to the experts. Often the line between scientific and trans-scientific issues is blurred: in fact, the essence of the matter is often to define just where the line between the

3 Polanyi, Michael, " The Republic of Science: Its Political and Economic Theory ", *Minerva*, I, 1 (Autumn, 1962), pp. 54–73.

4 Brooks, Harvey, " The Federal Establishment for Science and Technology: Contribution to New National Goals ", Conference on Research in the Service of Man: Biomedical Knowledge, Development, and Use, sponsored by the US Senate Committee on Government Operations, Oklahoma City (Washington, DC: US Government Printing Office, 1967), pp. 57–64; also *The Government of Science* (Cambridge, Mass.: The MIT Press, 1968).

two lies. Thus the experts consider public intrusion into the scientific parts of the debate by the uninitiated as obfuscatory; on the other hand, the public's involvement helps force a delineation between science and trans-science.

To take an example, safety of nuclear reactors can be answered definitively by science. Thus all would agree that, if every safety rod in a boiling water reactor were to fail at the same time as the turbine tripped, a catastrophe would ensue unless additional counter-measures were taken. This is a strictly scientific question which may be decided by the methods of science; and, in the case mentioned, the scientific facts are indisputable. Thus to the experts public discussion of this strictly scientific issue could only cause confusion, since science already gives an unequivocal answer.

On the other hand, the question of whether all the safety rods can ever fail simultaneously is trans-scientific. Here the experts disagree, and the question is really unanswerable: though all who have studied the matter will agree that the probability of failure is extremely small, some will insist that the event is incredible, others that it is not. This second question, whether the postulated initiating event is credible, is trans-scientific: experts possessing sound credentials disagree. Here public discussion helps to remind us that science can say little about the matter and that its resolution requires non-scientific mechanisms.

The public discussion of trans-scientific questions like the probability of a reactor accident runs the risk of introducing exaggeration and distortion into the actual situation. Discussion of the simultaneous failure of all safety systems in a reactor at a crucially important juncture is essential to the technical assessment of the reactor—if for no other reason than to design counter-measures which will minimise the probability of such events ever taking place. Yet, taken out of context, such discussion can sometimes cause great confusion, if not panic. There develops an accumulation of contingency: each unlikely event connected with a reactor, once it becomes a matter of public discussion, seems to acquire a plausibility which goes much beyond what was originally intended when it was more cautiously formulated by scientifically trained persons. In consequence, reactors now, at least in the United States, are loaded down with safety system added to safety system—the safety and emergency systems almost dominate the whole technology.

By contrast, in the Soviet Union, where the public does not have an automatic right to be informed about or to participate in scientific and technological debate of this sort, the technology of reactors is rather less obviously centred around safety. Until recently, Soviet pressurised water reactors had no containment shells. The Soviet engineers insisted that the primary systems were built so ruggedly that a catastrophic accident of the sort which the containment shell is intended to deal with was incredible; and, moreover, that the containment shell would not be effective if the accident were severe enough. There was here a divergence between the

American and the Soviet views, both with respect to the effectiveness of containment shells, and with respect to how safe is safe enough. One can attribute these differences simply to the existence of the very influential Advisory Committee on Reactor Safety in the United States. However, I would not underrate the importance of the difference in degree of access of the public to the technological debate in the Soviet Union and in the United States. In my view, the added emphasis on safety in the American systems is an advantage, not a disadvantage; and, in so far as this can be attributed to public participation in the debate over reactor safety, I would say such participation has been advantageous. Recently, the Soviet engineers have reconsidered the matter, and the newer Soviet pressurised water reactors are housed in containment shells. The extent to which the American debate has influenced this change in policy is hard for an outsider to judge.

What are the responsibilities of the scientist in trans-scientific debate? Though the scientist cannot provide definite answers to trans-scientific questions any more than can the lawyer, the politician or a member of the lay public, he does have one crucially important role: to make clear where science ends and trans-science begins. Now this is not at all easy since experts will often disagree as to the extent and reliability of their expertise. Yet, as the current debates over the environment demonstrate, scientists often appear reluctant to concede limits to the proficiency of their science. As I have already mentioned, the argument about low-level radiation insult would have been far more sensible had it been admitted at the outset that this was a question which went beyond science. The matter could then have been dealt with, initially, on moral or aesthetic grounds.

Beyond this, the scientist possesses a unique knowledge which borders the trans-scientific issues. It is this knowledge that he can and must use to inject discipline and order into the often chaotic trans-scientific debate. Thus, even in trans-scientific debate, which inevitably weaves back and forth across the boundary between what is and what is not known and knowable, confrontation between scientists of opposing ethical or political positions is desirable. But, as the extraordinary debate over the anti-ballistic missile demonstrated,[5] scientists must exercise all the canons of scientific discipline in such a confrontation: if they do not adhere to these canons then, as Robert L. Bartley has plaintively asserted, " If scientists do not scrupulously guard a certain minimum of detachment and self-restraint, what do they have to offer that the next man does not? If all questions are political, why not leave them all to the politicians? "[6]

[5] See " The Obligations of Scientists as Counsellors: Guidelines for the Practice of Operations Research ", *Minerva*, X, 1 (January, 1972), pp. 107–157.

[6] Bartley, Robert L., " When Science Tangles With Politics ", *The Wall Street Journal*, 12 October, 1971.

The Impact of Trans-Science on the Republic of Science

Since the border between trans-science and science is elusive, it seems clear that the public will inevitably become involved in debates which possess scientific as well as trans-scientific components. Could such participation in science by the non-certified tend to weaken the republic of science, citizenship in which is rigorously certified? If the public has a right to debate the details of reactor designs, then why not extend that right to the debate on whether nuclear physics or high-energy physics should be supported more heavily? If it has the right to debate the use of pesticides in agriculture, then should it not have the right to debate whether or not we should do experiments that might lead to human cloning or which might disclose racial differences in intelligence? And if the unaccredited public becomes involved in debates on matters as close to the boundary between science and trans-science as the direction of biological research, is there not some danger that the integrity of the republic of science will be eroded?

Another aspect of the public's intrusion in scientific debate is the tendency to expose such debate to public scrutiny, and thus to public debate, before " all the facts are in ". A good example of this is the recent incident in the United States concerning the adequacy of emergency core cooling systems in pressurised water reactors. The emergency core cooling system springs into action in the very unlikely event that the regular cooling system fails to deliver water to the hot core of a reactor. Recent experiments at Idaho Falls raised questions as to the reliability of the emergency system; but these experiments, performed on a very small scale, have been severely challenged by experts in the field.

The issue here is scientific, and it clearly can be answered by the usual mechanisms of science—experiment, additional analysis, challenge and counter-challenge by those who have intimate knowledge of the matter. But because the emergency core cooling system is so closely tied to the safety of reactors, the scientific debate has become a matter of intense public discussion and concern. Public pronouncements as to the outcome of the scientific argument are made, especially at hearings before reactor licensing boards; and the political pressure generated thereby may force an improper decision before the scientific debate has come to a proper conclusion.

Another possible danger of the public's involvement in scientific debate is illustrated by the Velikovsky incident.[7] To much of the public, I dare say, Velikovsky's treatment by the scientific community smacks of Galileo's treatment at the hands of the Inquisition. To a scientist, Velikovsky is not to be taken seriously because he did not conform to the rules of procedure of the republic of science; to the public, he is the

[7] Immanuel Velikovsky created a sensation during the 1950s in the United States with his book, *Worlds in Collision* (Garden City, N.Y.: Doubleday, 1950). See Polanyi Michael, " The Growth of Science in Society ", *Minerva*, V, 4 (Summer, 1967), pp. 533–545.

victim of an arrogant elite. The non-scientific public came close, in the Velikovsky case, to demanding the right to pass judgement on scientific questions.

In the past, when science depended less completely upon the public for its support, it was perhaps not so serious that the lay public's views on scientific questions were ignored by the scientists. Today, however, one wonders whether science can afford the loss in public confidence which the Velikovsky incident cost it. The republic of science can be destroyed more surely by withdrawal of public support for science than by intrusion of the public into its workings.

That the republic of science may be compromised by encroachment from the public is probably an exaggeration: there will always be a part of science that is so unambiguously in the realm of science that it would be absurd to think of an encroachment by the uninitiated. But whether or not the republic of science is weakened, the die is cast. In the final analysis, no matter what the disadvantages of public access to technological and trans-scientific debate, I believe we have no choice. In a democratic society, the public's right of access to the debate in the sense of being informed about it and participating in it is as great as the public demands it to be. Especially where experts disagree, the public has little choice but to engage in the debate at an earlier stage than the experts themselves find convenient or comfortable. Questions with strong scientific content which impinge too forcefully on the public concern inevitably become incorporated in the republic of trans-science.

The late Professor Harold Laski once said:

> . . . special knowledge and the highly trained mind produce their own limitations. . . . *Expertise* . . . sacrifices the insight of common sense to intensity of experience. . . . It has . . . a certain caste-spirit about it, so that experts tend to neglect all evidence which does not . . . belong to their own ranks. . . . where human problems are concerned, the expert fails to see that every judgment he makes not purely factual in nature brings with it a scheme of values which has no special validity about it.[8]

We in the technological and scientific community value our republic and its workings. But when what we do transcends science and when it impinges on the public, we have no choice but to welcome the public—even encourage the public—to participate in the debate. Scientists have no monopoly on wisdom where this kind of trans-science is involved: they will have to accommodate to the will of the public and its representatives. The republic of trans-science, bordering as it does on both the political republic and the republic of science, can be neither as pure as the latter nor as undisciplined as the former. The most science can do is to inject some intellectual discipline into the republic of trans-science; politics in an open society will surely keep it democratic.

[8] "The Limitations of the Expert", *Harper's Magazine* (December, 1930), quoted in Green, Harold P., *op. cit.*, p. 136.