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JOHNSON SEEKS NEW DISARMAMENT STEPS

At the reopening of the 18-nation Geneva disarmament Conference on January 21, President Johnson appeared to have thrown a ten-gallon hat full of proposals into the negotiating arena. His message, read at the opening session by U.S. delegate William C. Foster, set forth five topics for negotiation (and sub-items) designed to extend and formalize the current slowdown in the arms race.

The biggest suggested step was a "verified freeze" of the numbers and types of vehicles, mainly long-range bombers and missiles, capable of delivering strategic nuclear weapons. While the idea of such a freeze was implicit in the first stage of the U.S. general disarmament plan submitted in April 1962, the offer to negotiate it separately is new, reflecting the trend of U.S. policy toward limited, piecemeal agreements.

There were hopes that the verification aspects could be handled so as to minimize conflict with Russian sensitivity about inspection. Since only production of large planes and missiles would be covered, verification might be limited to watching the output of factories, without attention to military bases.

Mr. Johnson's other proposals were:

—A prohibition of the threat or use of force between nations. This was an extension of a Soviet proposal renewed in Mr. Khrushchev's New Year's message. The Russian version had, as usual, exempted from the ban "wars of liberation" of several types.

—A verified agreement halting all production of fissionable materials for weapons (essentially a repetition of long-standing U.S. proposals).

—Establishment of a system of observation posts (presumably mainly in Europe) to keep watch on military movements and thus reduce the chance of war by accident, miscalculation, or surprise attack.

—Agreement not to transfer nuclear weapons into the national control of countries which do not now have them.

—Acceptance by the major nuclear powers of increasing international inspection of their peaceful nuclear activities.

—A verified ban of all nuclear tests. (N.Y. Times, 1/22.)

The Johnson Administration has already made unilateral moves along some of these directions. Missile procurement is sharply reduced in the proposed 1965 budget. Production of fissionable materials for weapons is also being cut, by 25%. Plans call for reducing plutonium production by shutting down three of the nine reactors at the AEC's Hanford plant, and one of the five reactors at the Savannah River plant. In addition, the electrical consumption of the three gaseous diffusion plants at Oak Ridge, Paducah, Ky., and Portsmouth, Ohio, will be reduced by 25%. The effect will be to reduce by about the same fraction the plants' output of enriched uranium.

Both the U.S. and Soviet Union have announced that defense spending will drop in their next budgets (see Dec. Newsletter). Thus the arms race is seemingly being moderated without formal agreement, by what Mr. Khrushchev has called a "policy of mutual example."

NEW DIRECTION FOR SPACE BUDGET — DOWNWARD

In keeping with the Administration's economy drive, the President's budget message requested $5.3 billion for NASA, for fiscal 1965, a $400 million reduction from last year's request. In addition, the President asked for $141 million more space dollars which were authorized but not appropriated during fiscal 1964. Since its creation in 1958, NASA has flourished and grown with large annual increases in its budget. Now the space budget is leveling off sooner than had been expected or planned. The result will be a stretching out of plans for manned exploration of the moon and a cutting down of programs for scientific exploration of space. Whether the total of $5.4 billion will be enough to purchase a "first-class ticket" to the moon's surface has become a subject for debate. NASA officials are contending that they will require every penny of the President's request or the 1970 man-on-the-moon target date set by the late President Kennedy will be missed.

Two-thirds of the space agency's budget request is for the manned space flight program, including all of the supplemental $141 million, which the President said was needed to regain time lost on the moon program because of heavy space budget cuts made by the Congress in 1963 (N. Y. Times, 1/5 and Wash. Post, 1/22; see also Dec. Newsletter.)

PROBLEMS OF DEFENSE AGAINST BALLISTIC MISSILES

by Freeman J. Dyson

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It is no accident that ballistic missile defense has become one of the major issues confronting the United States and the Soviet Union. We have seen how the question of BMD came to dominate the debate over the ratification of the test ban treaty. It is likely to dominate in a similar way any attempts at arms control or disarmament which may in future come close to the point of realization. It is necessary that scientists and other people who are concerned with disarmament should take BMD seriously and should avoid the over-simplified views which are at the moment prevalent. On one side, many people believe that BMD is necessary to our security; on the other side, many believe that BMD is a dangerous illusion. The truth is certainly much more complicated.

There are three whole ranges of problems connected with BMD, which we may call technical, military, and political. To understand the issues, one must examine in detail all three types of problem. I obviously cannot discuss any of these problems adequately in a few paragraph. I shall only try to give all three types of problem equal emphasis, to show that in neglecting any one of them we may reach very wrong conclusions. Let me begin with a few technical facts.

TECHNICAL FACTORS

1. The technical progress which has been made in BMD development is extremely impressive. The people who are doing the technical work are enthusiastic about what they have done, and believe they can do even better in future. Technical problems, which were five years ago considered severe, are now either solved or close to being solved. There is no doubt that the euphoria of the successful technician has played a large role in making BMD look more promising now than it did five years ago. It is easy to understand the enthusiastic statements of Marshal Malinovsky and other Russian leaders on this basis.

2. BMD is immensely expensive. Costs are quoted from 10 billion dollars upward. A system which tries seriously to protect a big country is likely to cost 100 billion dollars by the time it is finished.

3. The state of the art is constantly changing. This means that a massive BMD system might very well be made obsolete by changes in the offensive threat during the time it is being built.

An enormous literature exists in which the technical problems of BMD are discussed in detail. Most of this is, unfortunately, classified. The best source of unclassified information is the Congressional Record; for example the hearings before the Senate Armed Services Committee in February and March 1963, and the test ban hearings of July 1963.

MILITARY PROBLEMS

Next I may mention a few of the military problems.

1. Before deciding whether or not a BMD system is useful, one must have some point of view concerning the types of situation with which it is supposed to deal. Generally speaking, American and Soviet military planners seem to be plan-

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ning for totally different kinds of war. The American-style war is short; it consists of little more than a single, well-organized and massive attack, possibly followed by additional attacks, but not extending in time longer than a few days or weeks. A Russian-style war is typically a long and messy affair, with both sides carrying on a bitter and disorganized struggle, probably for many years. It is hard to say which picture of war is more realistic. In general, the American-style war favors the attack, while the Russian-style favors the defense. Thus it is to be expected that BMD will generally look better to the Russians than it will to us.

2. It is probably a permanent feature of BMD systems that their performance will be unpredictable. Even a system which can defend a city "on paper" may well fail to do so in practice because of human failures, confusion, cowardice, or breakdown of equipment. It is totally impossible, even disregarding the atmospheric test ban treaty, to give a BMD system any worthwhile practice in peacetime. Its inherent unpredictability is a serious drawback to BMD in the eyes of American strategic planners who try to make war into something calculable. For Russian planners, the unpredictability is not such a drawback since they do not believe that war is calculable anyhow.

For a good general survey of Soviet military thinking, I recommend the volume "Soviet Military Strategy", edited by Marshal Sokolovskii and now available in English translation.

POLITICAL ISSUES

Lastly, I come to the political problems connected with BMD. The main political problem is the intense pressure which exists on both sides to duplicate anything which the other side does. It is a fact of life that, as soon as the Russians begin the construction of a serious BMD system, the pressure on the American government to follow suit will be almost irresistible. The prevalent belief in the United States is that a Soviet BMD system would indicate a Soviet attempt to nullify our second-strike force and thereby present a serious threat to our security. In the test ban hearings the intensity of fear of a Soviet BMD system was very strikingly shown. I wish to argue that a Soviet BMD system would, in fact, be built with entirely different objectives in mind.

The following are three of the many political factors which in my judgement would lead Soviet leaders to build BMD:
1. The balance of power in the Russian military establishment, as in our own, rests largely on budgetary considerations. Our strategic air command has always had a larger budget than our air defense command, and a correspondingly larger share of political influence. In the Soviet Union, the big budgets and the political pull have belonged to the defensive commands, particularly to the army and air defense commands. To preserve the internal balance of power, it was almost inevitable that as the external threat changed from airplanes to missiles, the Soviet air defense command should become heavily involved in missile defense. If Khrushchev wished to call a halt to BMD in the Soviet Union, he would probably find it necessary to change the military power structure in favor of his offensive missile commanders who have hitherto been treated rather shabbily. There are many reasons why we should fear rather than welcome such a shift.

2. There is a strong tradition in the Soviet Union of using bluff as a defensive weapon. The bomber-bluff of 1955 and the ICBM-bluff of 1960 are well-known examples. The Soviet leaders are able to tolerate a position of numerical inferiority if it can be hidden by brave words and effective secrecy. Soviet BMD development falls into this same pattern. Clearly BMD is an excellent bluff weapon, since nobody will ever know, short of war, how good or bad it really is. The historic American reaction to Soviet bluff is to demolish it as rapidly and as publicly as possible; for example the ICBM-bluff was demolished in 1960 by the humiliating disclosure of the results of U2 reconnaissance. A much more intelligent American reaction would be to preserve the bluff; it is strongly to our advantage to be facing a Soviet bluff rather than a militarily real defense, even if our intelligence is not good enough to tell the difference.

3. Soviet political leaders and military experts have never accepted the distinction between deterrence and defense. Among American disarmament experts it has become almost obligatory to make this distinction. Many of our scientists are strongly opposed to BMD, because they consider that defense and deterrence are necessarily incompatible. Their argument is that deterrence against war depends on both sides being defenseless against a massive attack on populations. This American dislike of defense is, of course, connected with the idea of war as something short and calculable, which I discussed earlier. The Russians have never believed that deterrence of war depended primarily on the outcome of an initial attack. They relied on the fact that in the long run neither side can defeat the other, and that nobody is likely to begin a war which he knows he cannot finish. Soviet-style deterrence consists in having the power and the will to drag a war out indefinitely into the long and messy phase in which the traditional Russian strategy of endurance and attrition can operate successfully. They have never seen any inconsistency between this kind of deterrence and a maximum emphasis on all kinds of defensive weapons including BMD.

This is a very brief and sketchy summary of some of the important factors that must be included in any assessment of BMD. My main message is that the strategic and political purposes of BMD are quite different in the Soviet Union from what they are in the United States. It is very likely that Soviet BMD is well suited to Soviet purposes, whereas American BMD may be quite unsuited to American purposes. A Soviet BMD system may be highly reassuring to them and not at all threatening to us, while an American BMD system may look threatening to them and not at all reassuring to us. Any analysis of the problem which treats the two sides symmetrically is far too simple to be correct.

FALLOUT FROM U.S. UNDERGROUND TESTS?

Another dimension was added to the fallout problem in an article in the January 10th issue of Science. Dr. E. A. Martell, radiochemist at the National Center for Atmospheric Research, Boulder, Colo., has concluded that the record I-131 fallout in the U.S. in 1961 and 1962 was due to the venting of underground explosions in Nevada. Fallout had previously been attributed to atmospheric tests by the U.S. and the Soviet Union. Dr. Martell, who based his conclusions on wind patterns and the nature of the fallout, suggests that underground tests are either more difficult to contain than previously thought or that no serious effort was made to contain them. Even with underground tests that are generally contained there can be selective venting of I-131.

The AEC and Weather Bureau took sharp issue with these views, definitely attributing the fallout to U.S. tests over Christmas Island and Soviet tests at the arctic site, Novaya Zemlya. They further claimed that since last spring there have been over a dozen underground tests, some of which vented, and the nationwide milk surveys have reported no I-131 since June.

Apart from health hazards, venting of underground explosions may lead to violation of the Test Ban Treaty recently signed. While permitting underground tests, the Treaty does ban any test that releases radioactive debris on the territory of other nations. In June 1962, I-131 increased in the milk in Spokane, Wash. following an accidental venting in Nevada. Spokane is only 100 miles from Canada. Since 1962, at least 16 underground tests have vented, one in full public view.

The venting problem is emphasized because of growing concern over the health hazard of I-131, particularly to children whose thyroids may be highly vulnerable. I-131 enters the food chain through milk from cows grazing on contaminated pasture. Children, of course, consume more milk than adults.

Not for Publication

FAS ELECTIONS — 1964-1965

Invitation for Additional Nominations by the Membership

Listed below are the nominations for FAS Chairman and Vice-Chairman for 1964-1965, prepared by the Elections Committee (Allen I. Janis, Chairman; Richard S. Preston, Lincoln Wolfenstein, and Gary Felsenfeld). In accordance with the By-Laws, FAS members may nominate by petition containing the endorsing signatures of 10 members and the consent of the nominee to serve if elected. Additional nominations should be sent **by February 20** to the FAS Elections Committee, c/o Dr. Allen I. Janis, Physics Dept., U. of Pittsburgh, Pittsburgh 6, Penna.

The FAS membership will also elect 12 delegates-at-large for two-year terms on the national council. The Elections Committee's proposed nominees for delegates-at-large are listed below. FAS members may make additional nominations by petition containing five signatures and the nominee's consent. Additional nominations should be sent to the Elections Committee (at the above address) **by February 20.**

The terms of the following delegates-at-large will **not** expire until the spring of 1965: Ruth Adams, Peter Axel, Donald G. Brennan, Gary Felsenfeld, W. A. Higinbotham, Gerald Holton, Ernest C. Pollard, John R. Stehn, Stanislaw Ulam, Robert Williams, Hugh C. Wolfe, and Lincoln Wolfenstein.

In addition to the 24 delegates-at-large, the FAS Council will consist of the Chairman, Vice-Chairman, 2 past chairmen, and 1 delegate from each of the ten chapters: Berkeley, Brookhaven, Chicago, Los Alamos, Los Angeles, Philadelphia, Pittsburgh, Schenectady-Troy (MASE), Stanford, and Washington. Chapter members will also vote for delegates-at-large.

NOMINEES FOR CHAIRMAN
Peter G. Bergmann, Yeshiva U.
John S. Toll, U. of Maryland

NOMINEES FOR VICE-CHAIRMAN
Jack Orloff, N.I.H.
Cameron B. Satterthwaite, U. of Illinois

NOMINEES FOR DELEGATE-AT-LARGE
Dan I. Bolef, Washington U. (St. Louis)
Owen Chamberlain, U. of Calif.
William C. Davidon, Haverford
John T. Edsall, Harvard
Bernard T. Feld, M.I.T.
Maurice S. Fox, M.I.T.
Martin Gellert, N.I.H.
Caroline L. Herzenberg, Ill. Inst. of Technology
Cyrus Levinthal, M.I.T.
Hans J. Morgenthau, U. of Chicago
Jay Orear, Cornell
Charles E. Osgood, U. of Illinois
Arthur H. Rosenfeld, U. of Calif.
Walter Selove, U. of Penna.
Louis B. Sohn, Harvard Law School
Peter H. von Hippel, Dartmouth Medical School

Also nominated are the losing candidates for chairman and vice-chairman. The elections committee announces that any voter who wishes to have both candidates for each office serving FAS, may so indicate on his ballot.

SMOKING AND HEALTH

"On the basis of prolonged study and evaluation of many lines of converging evidence, the Committee makes the following judgment: Cigarette smoking is a health hazard of sufficient importance in the United States to warrant appropriate remedial action."

These words summarized the long-awaited, carefully-weighed conclusions of the U. S. Surgeon-General's Advisory Committee, in its report on *Smoking and Health,* made public on January 11 ($1.25 from the Government Printing Office, Washington, D. C.). For over a year, the Committee had worked at its assigned task, "an objective assessment of the nature and magnitude of the health hazard" associated with the use of tobacco. In addition to its emphatic answer that the hazard was sizeable, the Committee report drew the important conclusion that "There is no evidence to establish the fact that filters have done anything to reduce the health hazards of cigarette smoking."

BACKGROUND

The Committee consisted of ten eminent American scientists selected by the Surgeon-General from a list of men approved by the Tobacco Institute (an organ of the industry). Two of the final ten were proposed by the Tobacco Institute; the Committee included pathologists, internists, other medical specialists, a statistician, and an organic chemist. The prime requisite for selection of the men was objectivity and lack of previous commitment on the question of smoking and health.

In reaching its conclusions, the committee did not do any original research, but rather evaluated three main types of studies: 1) Animal experiments studying the effects of substances in tobacco smoke and tars with regard to carcinogenesis, suppression of ciliary action and damage to mucus glands; 2) Clinical and autopsy studies relating smoking habits to certain cellular changes such as loss of ciliated cells, thickening of basal membrane and presence of atypical or pre-malignant cells in the respiratory system; 3) Population studies—29 retrospective and seven prospective studies relating death rates to the individual's smoking history.

SOME MAIN FINDINGS

In the table reprinted below, the Report presented the combined experience reflected in the seven prospective studies, which were all consistent. "Expected deaths" were calculated using the death rate for non-smokers with appropriate corrections, such as for age. Cancer of the lung has the most striking mortality ratio, and on the basis of this and other evidence the Committee made the declaration that "Cigarette smoking is causally related to lung cancer in men; the magnitude of the effect of cigarette smoking far outweighs all other factors." (The Report noted that data for women, though less extensive, point in the same direction.) "The risk of developing lung cancer increases with the duration of smoking and the number of cigarettes smoked per day and is diminished by discontinuing smoking." Coronary artery disease is numerically the most significant source of increased mortality in smokers. "Although the causative role of cigarette smoking in deaths from coronary disease is not proven, the Committee considers it more prudent from the public health viewpoint to assume that the established association has causative meaning than to suspend judgment until no uncertainty remains."

Cigarette smoking is a significant factor in the causation of several other cancers. It is a much more significant cause of broncho-pulmonary diseases such as chronic bronchitis and emphysema than is atmospheric pollution or occupational exposure. Pipe smoking appears to be causally related to lip cancer. For cigar and pipe smoking combined, there is a suggestion of high mortality rates for cancer of the mouth, esophagus, larynx and lungs. However, these rates are based on a small number of deaths.

REACTIONS TO THE REPORT

Spokesmen for the tobacco industry responded to the report by emphasizing the need for more research, especially on filters, and offering to assist the government in this sphere. Meanwhile, the American Tobacco Company (one of whose officials previously described health statements on cigarette packages as "fouling your own nest") proposed marketing a new low-tar and nicotine brand with tar and nicotine contents listed on the package.

The Federal Trade Commission proposed labeling each package and carton of cigarettes with a warning that smoking is a health hazard. The FTC also proposed much closer control of advertising, eliminating unsubstantiated claims about the merits of smoking or the decreased health hazard associated with a special filter or brand. A public hearing on the proposals has been set for March 16.

Reactions in Congress split into two groups. Representatives of the tobacco states were led by Rep. Cooley (D-N. Carolina), who submitted a proposal for a Government research program "to accomplish maximum assurances of health in the smoking and enjoyment of tobacco." Sen. Neuberger (D-Oregon) led others by introducing two bills, one requiring cigarette packages to bear a health warning and the other calling for a federally financed program to educate the public on the dangers of smoking. (N. Y. Times & Wash. Post, 1/19.)

TABLE: Expected and observed deaths for male smokers of cigarettes only and mortality ratios in seven prospective studies.

Underlying cause of death	Expected deaths	Observed deaths	Mortality ratio
Cancer of lung	170.3	1,833	10.8
Bronchitis and emphysema	89.5	546	6.1
Cancer of larynx	14.0	75	5.4
Oral cancer	37.0	152	4.1
Cancer of esophagus	33.7	113	3.4
Stomach and duodenal ulcers	105.1	294	2.8
Other circulatory diseases	254.0	649	2.6
Cirrhosis of liver	169.2	379	2.2
Cancer of bladder	111.6	216	1.9
Coronary artery disease	6,430.7	11,177	1.7
Other heart diseases	526.0	868	1.7
Hypertensive heart	409.2	631	1.5
General arteriosclerosis	210.7	310	1.5
Cancer of kidney	79.0	120	1.5
All causes	15,653.9	23,223	1.68

NUCLEAR EXPLOSIVES FOR RAILWAY PASS AND CANAL?

A plan to use 22 nuclear explosions to dig a railway and highway pass through a range of California hills has been submitted to the AEC. The project calls for the blasting out of 68 million cubic yards of earth in the Mojave Desert Hills just north of Amboy, Calif. The cut would be 350 feet deep at the deepest and would average 325 feet in width. A report on the project was prepared jointly by the AEC office in Berkeley, the California Division of Highways and the Santa Fe Railway. The realignment of the railway route would eliminate 15 miles of track, reduce the grade and speed up Santa Fe's transcontinental freight service. According to the preliminary study, the cut would cost about $21 million if made by conventional methods and $13 million if dug with nuclear explosions. The nuclear blasts would yield the equivalent of 1.8 million tons of TNT (Wash. Post, 12/24).

More recently, the feasibility of using nuclear explosives to blast a new Central American canal has attracted attention, both pro and con. The Joint Congressional Committee on Atomic Energy has received a letter from physicist Gerald Johnson saying that nuclear explosives could be used to dig a canal far more cheaply and with much less fallout than hitherto thought possible. Johnson, a former Defense Department official, is associate director of the AEC's Lawrence Radiation Laboratory, in charge of its peaceful explosive research effort. His letter was written to JCAE Chairman Pastore in response to a request from the Chairman for a new assessment of using nuclear explosives to dig a new canal. AEC officials have indicated that the use of nuclear devices to blast a new canal might violate the limited test ban treaty unless consent were granted by all signatories of the treaty. Russia would be unlikely to facilitate U. S. aims in this direction (Wash. Post, 1/21).

NEW YORK LOSES A REACTOR WHILE MEXICO GAINS ONE

The Consolidated Edison Co. has deferred its plans to build a nuclear power plant in the Ravenswood section of Queens, New York City. The move came as an aroused citizenry was loudly protesting the building of the plant on the grounds of possible radiation hazards. Nevertheless, Consolidated Edison denied that it had withdrawn its application because of political and public opposition to the project. A company spokesman said that the plans were deferred because the company expected to buy large amounts of hydroelectric power from Canada on an economically favorable basis. The company indicated that it might again apply to the AEC for permission to build a similar plant within New York City in the years ahead (N. Y. Times and Wash. Post, 1/7).

Last month, an agreement between Mexico, the U. S. and the International Atomic Energy Agency was announced, giving Mexico its first atomic reactor. A TRIGA research reactor will be sold to the Mexican government by the General Dynamics Corporation, and the U. S. will give Mexico about 45 pounds of uranium fuel to run the reactor. Safeguards to insure that the nuclear material is used only for peaceful purposes will be applied by the IAEA. The reactor will be owned and operated by the Mexican National Nuclear Energy Commission. It will be located at a new facility at Salazar, near Mexico City (Wash. Post, 12/19).

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The FAS, founded in 1946, is a national organization of scientists and engineers concerned with the impact of science on national and world affairs.

EFFECTS OF SCALE ON MODERN SCIENCE AND TECHNOLOGY

by ALVIN M. WEINBERG

(The address reprinted below was given at the annual meeting of the Society for Social Responsibility in Science, Mohonk Lake, Sept. 7, 1963. Dr. Weinberg is Director of the Oak Ridge National Laboratory.)

My purpose in these remarks is to revive and bring up to date an observation about modern science and technology that the great mathematician John von Neumann made in 1955. von Neumann, in an article in *Fortune* called "Can We Survive Technology?", pointed out that modern technology and science have become so big that in many cases they have rendered our geographic and political units—fragmented as they are by tradition—obsolete. He suggested that unless the world accommodated to this essential reality of modern technology by closer cooperation between political units, if not reorganization into much larger units, it could not survive for long. I shall try to trace the course of some elements in this trend in the seven years since von Neumann wrote. I shall emphasize that not only our *political* organizations are being rendered obsolete by the march of *military* technology, but also our *economic* organizations are being rendered obsolete by the march of *civilian* technology; and that, hopefully, our science as well as our technology are driving the world toward an unaccustomed unity.

THE CASE OF NUCLEAR REACTORS

I shall illustrate this phenomenon first with some recent developments in nuclear reactors. A nuclear reactor is, in principle, a practically unlimited energy source: the amount of power that can be drawn from the reactor is limited only by the size of the heat exchange equipment. Thus the cost of a nuclear reactor increases as its size increases, but not as fast as its size: the reactor itself, its instrumentation, its shield, etc., hardly increase at all as the output of the reactor increases; the heat exchange equipment increases with heat output, but, like most large-scale equipment, probably at a slower rate than the heat output itself. That the unit cost of nuclear reactors, like conventional power plants, decreases with increasing size has been known for a long time. It is tempting to extrapolate the cost curves: at 3000 Mw(th) the capital cost of a reactor is estimated to be about $30 to $40/kw(th); at 10,000 Mw(th) the cost comes down to $14 to $18/kw(th) and at 30,000 Mw(th) the cost comes down to $10 to $13/kw(th). If electricity were produced from such Gargantuan reactors, the estimated capital cost per kilowatt of electricity would also be phenomenally low—possibly less than $120/kwe in sizes of 8000 Mwe.

The other major component of cost in the nuclear reactor, the fuel cycle cost, also seems to fall sharply as the size of the system increases. The fuel cycle cost is made up of two major costs—fabrication and burnup, and chemical processing Both costs fall sharply as scale is increased, at least for reactors that use natural uranium or reactors with very good conversion of U^{238} into Pu^{239}. Both fabrication and chemical processing lend themselves well to mass production. If these enterprises are conducted on a large enough scale, then the costs approach more and more nearly the cost of the raw materials: chemicals and power. Such behavior of the cost curve has been strikingly demonstrated at the K-25 diffusion plant; because U^{235} is separated on such an enormous scale, a gram of separated U^{235} now costs only about four times as much as its initial cost as unseparated isotope. Estimates based on demonstrated performance of the huge fabrication and reprocessing plants at Savannah River and at Hanford suggest that if a standardized fuel element were used, and reprocessing could be done for a complex of 25,000 or 50,000 Mw of reactors, the fuel cycle costs for certain nuclear reactors could be as low as one-tenth or less the energy cost of coal.

DESALTING THE SEA

Thus there seems to be one surprisingly direct and simple way to make nuclear energy competitive, and more than competitive, with energy from coal: this is to make the energy-producing units large, considerably larger than can now be accommodated by most existing electrical grids. We are thus faced with the tantalizing dilemma: we see how

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to make nuclear energy cheap by making it in very large chunks, but our social organizations, fragmented as they are, prevent us from exploiting nuclear energy on the most rational scale. Two ways out of the dilemma are possible: the first, due to R. P. Hammond of Los Alamos, is to try to find some use, that is not tied to the existing sizes of utilities or national electrical grids, for really large blocks of very cheap heat from nuclear reactors. He has pointed out one such use—large-scale desalting of the sea. Desalting the sea by multiple-effect distillation lends itself naturally to using heat from very large reactors because the amounts of heat needed are enormous and the average load factor is high, but demand need not be firm. These characteristics make the marriage of large reactors and desalting of the sea natural; Dr. Hammond believes the cost can possibly be brought down to the range of interest for agricultural purposes: less than 10¢/1000 gallons, particularly if some electricity is sold as a by-product. He envisages a sort of nuclear coastal region development centering around a large reactor that supplies both cheap electricity and cheap water.

The other possibility would be to merge national electrical grids even more completely than now and, perhaps more practically, uniformize reactor technology throughout big parts of the world. Merging of grids is a step now being taken in response to the trend toward bigness in ordinary electric power generating technique: the largest single turbo-generator and boiler is now rated at about 1,000,000 kwe, and few national grids in Europe can accommodate such big units. Evidently full merging of grids implies, in the long run, profound changes in the political climate: neighbors will have to trust each other far more than they have in the past.

The imperative of bigness is not confined to generation of energy; the transmission of energy also seems to be going in this direction. The trend in high-voltage transmission is to ever higher voltages—750 kev is now being studied seriously. Because the associated switch gear is so expensive, such systems look best when they carry very large loads. The discovery of high-field superconductors has opened new possibilities which, if proved feasible, would greatly emphasize this trend. One calculation suggests that an *economic* optimum is a cable of about 1-inch diameter carrying 100×10^6 kw—half the electricity of the United States! At this size electricity could be transmitted 1000 miles for less than 1 mill/kwh. A cable of this size, though logical enough on technical grounds, is absurd by present standards, but it is an extreme example of how the *intrinsic* scale of a modern technology might transcend the scale determined by our social and political organizations. Nevertheless, with electricity demand doubling every ten years, it is not completely out of the question to visualize some future huge centralized reactor stations, exploiting the economic gain in reactor scale I spoke of earlier, transmitting a hundred million kilowatts along a super-conducting cable distances of 1000 or even 2000 miles away. The interdependence of countries enforced by existing power grids would seem puny indeed if such monstrous grids became a reality: political and economic differences which, as the Common Market shows, are even now in process of crumbling, would melt even faster under the economic logic of such big-scale production and transmission of electricity.

INCREASED DANGERS

I turn now to a rather different, though related, matter—how the size of modern technology has greatly increased the penalty that society must pay if science commits an error. In the pre-scientific age, a single technological decision affected only the local situation. If an early steam engine spewed out too much smoke, this was a nuisance, not a disaster. Even if an imprudent chemical operation denuded the area—as happened around Docktown, Tenn. as the result of copper smelting—the damage was local and eventually could be repaired.

But the enormous increase in energy concentration represented by the new energy source, and the resulting integration of energy production, has greatly magnified the social harm that follows from technological or scientific imprudence. Hammond's reactors are so big, and in some cases would represent such a large fraction of the energy supply of a country, that failure of one of them would cause considerable social discomfort. More important, a major nuclear accident in such a device, causing fission products to spread, could be a national calamity.

The scientists who design and build such devices are aware of their hazard, and they have, I believe, shown admirable foresight in coping with them. Thus, the "exclusion distance" of a reactor such as Hammond describes is about 77 miles, the "safe" distance to a population center is 150 miles. Such distances would make Hammond's devices practically unavailable. Schemes have therefore been devised for containing the reactors so that, regardless of the catastrophe that might befall the machine, the public would not be endangered. The most effective such scheme is double containment with iodine filtration. Since the hazard from fission-product iodine exceeds the hazard from rare-gas fission products, containing I-131 reduces the hazard by a factor of at least 20. By combining I-131 filtration with double containment, the hazard I believe can be reduced acceptably, and Hammond's reactors must be taken seriously.

Ordinarily, in discussing this aspect of the social responsibility of science, we stress the *recognizable* dangers to society that result if the scientist goofs. The tendency then is to put pressure on the technologist or scientist not to try his new schemes because of their evident danger. I believe this is the force of Rachel Carson's beliefs in respect to insecticides—and of David Lilienthal's in his intemperate blasts at the proposed Ravenswood reactor.

But there is another side to the argument—namely, that there are social consequences, sometimes of an even graver sort, if the technologist does nothing. The new technologies of abundance—abundant power, abundant water, abundant food—convey dangers with them. The new technologies are, I believe, mankind's only hope of buying the time necessary to stake off the Malthusian catastrophe. . . .

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