

This could conceivably cause a crop failure and bring our hypothetical enemy to his economic knees. First, we would have to be able to do it and we now cannot. Second, we would have to get them to hold still for it—this might not be possible. Third, world opinion, if the effort were discovered, and it almost certainly would be, would force the aggressor to desist, perhaps too late for that season, but the impact of world opinion might be such as to make such action unprofitable.

On the other hand it might just be possible to benefitiate the climate—this is the sort of thing I would like to be able to do—of the place to the point where the potential enemy could have such an adequate economic base that he would have too much to lose by engaging in war.

Let us assume that a large country was, because of overpopulation, poor soils and protracted drought, in such a position that it was a wasteland populated by starving hordes. With what is now known in agriculture, land management, water management, and weather modification, it might well be possible to help that country obtain a viable economic status and supply its own needs. In the end this might well result in improved world relations.

Whether to do this or not is a matter for that country involved to decide. On the other hand we might wish to help them. With their consent and cooperation one might call upon U.S. military forces to undertake a large share of the weather modification work because they would have the capability and equipment to do so.

The trained and disciplined personnel could do it more capably than an ad hoc collection of resources. Thus, the military could be used constructively in foreign affairs, doing the very things that the proposed treaty would not let them prepare for.

In a well run country the armed forces are a tool of the makers of foreign policy; we should keep this tool sharp and available.

#### DETECTION OF SMALL-SCALE VIOLATIONS AND ENFORCING TREATY

I should now like to address another aspect of such a treaty. Would small-scale violations be detectable? Would the treaty be enforceable? The answer to both questions is in doubt at the present time.

Unless adequate intelligence were available so that we could learn of the preparations and plans for such an adventure it is unlikely that a violation could be detected until it was too late. There is now no way to tell if a storm has been seeded.

It is true that the seeding agent might possibly be detected and identified. With what technology now exists, it is extremely difficult to do so because the air all over the world is so polluted by heavy metals that the augmentation of heavy metal content of rain caused by cloud seeding could not be told from that already present. The science of weather prediction is not yet so exact that small changes produced by weather modification could be detected. Were such changes on a subcontinental scale they would probably attract attention.

Were they to attract attention we should be faced with the problem of calling the malefactors on it. Would this be settled easily by diplomatic negotiation or would we be obligated to make them quit?

In order to prevent violation of such a treaty we would have to spend a fortune finding means of detecting such activity and proving that the treaty was not being obeyed.

An example comes to mind in the field of seismology where in order to detect violations of a treaty involving testing of nuclear weapons millions of dollars were spent developing a seismic detection system.

The technology developed to detect atomic explosions is in part applicable to earthquake work but the science of seismology dedicated to study of earthquakes received much less attention, and still does to a very large extent, in spite of the fact that a large earthquake anywhere in the country would be a civic and economic disaster of outrageous proportions.

#### WORK OF WITNESS' ORGANIZATION

In closing, I would like to thank you for the chance to make my ideas known and to acquaint you with the work of my organization. I feel that the things we have done have been good and have been a worthwhile expenditure of the Government's money and our time.

That we are in a Navy laboratory has facilitated the work we have done and I really feel that it probably would not have been done as soon had not the Naval Ordnance Test Station decided to go ahead in a new field that at the time was clearly of more general and humanitarian interest than military utility.

Eventually others would have done the same things and perhaps done them better. We have, however, been a force in shaping the direction in which weather modification in this country has gone and I believe that it was a good direction.

It has been a pleasure for us to work with the other Federal agencies in the development of their own programs, to use the things they turned out and to see them use ours. I believe you will agree with me that the humanitarian uses of the things we have done in a naval laboratory have been worthwhile. I would rather than take a negative attitude toward human activity of any sort to try to find a way to take advantage of it and I concur in your wisdom in that you have expressed a desire to use things for peaceful purposes and I would like to see a treaty, if such were written, where we could make optimum use of the resources of the country to carry out these worthwhile ends.

#### SUGGESTED CHANGES IN PROPOSED TREATY

Let me say that if we must have a treaty let us write another one eschewing all forms of violence as a means of settling disputes. If we can't do that, and if we must have the proposed treaty, let us so write it that—

1. Tactical use of geophysical weapons be permitted for the benefit and protection of our fighting forces.

2. Strategic use be limited, when and if it becomes a reality, to peaceful application by mutual agreement of the countries concerned and the concurrence of such neighbors as may also be affected.

3. That military forces be used in such constructive efforts if it is to advantage to do so.

Thank you.

Senator PELL. Thank you very much.

# DIFFERENCE BETWEEN TACTICAL AND STRATEGIC USES OF GEOPHYSICAL WEAPONS

What is the difference in your mind between the tactical use of geophysical weapons and strategic use?

Mr. ST. AMAND. Strategic use would be use that tended to upset the economy of another country for a long period of time, or to cause extensive damage to the crops of that country. Tactical use would be a situation where under battlefield conditions or in training exercises you could benefitiate the weather so you could operate better, you could make it a little bit worse so that the other side couldn't operate as well.

Senator PELL. Speaking to you as a scientist, what would be the watershed between the two?

Mr. ST. AMAND. It is a hard distinction to make.

Senator PELL. Is it possible to make it, do you think?

Mr. ST. AMAND. I would say that you could not draw a clearcut distinction. You might have to make the distinction on the basis of the size of the military operation and the consequences of failure and availability of other methods that you could use.

In general, tactical to a military person is that the tactical mission is something you use in day-to-day work with small groups and strategic things involve the use of larger areas.

Senator PELL. Would it be a question of relativity and interpretation, would it be very hard to be specific?

Mr. ST. AMAND. That will be indeed a challenge to the writers of the treaty.

## WITNESS' VIEWS ON WEATHER MODIFICATION

Senator PELL. About a dozen years ago you testified before the Senate Commerce Committee and at that point I gathered you are quite consistent in your views. You said and I quote—"A good deal of the work of the Naval Ordnance Test Station is aimed at giving the U.S. Navy and other Armed Forces, if they should care to use it, the capability of modifying the environment to their own advantage, or to the disadvantage of the enemy. We would regard the weather as a weapon and weather is as good a one as any."

This is basically your view?

Mr. ST. AMAND. This was basically my view and still is. The things we have done for the world at large have been spinoffs from our work and we were happier with those than we were with any other aspect of it.

## CAN WEATHER MODIFICATION BE USED AS WEAPON NOW?

Senator PELL. Has weather modification, in your view, reached the stage where it could be utilized as a weapon?

Mr. ST. AMAND. Say that again, please.

Senator PELL. Has weather modification already reached the stage where it could be used as a weapon?

Mr. ST. AMAND. Only in a tactical scale.

# KINDS OF MODIFICATION NAVAL ORDNANCE TEST STATION CONCERNED WITH

Senator PELL. Is your naval ordnance test station concerned with any other kinds of environmental or geophysical modification besides the instances you cited in your testimony of rainmaking, rain suppression and fog dispersal and hail?

Mr. St. AMAND. Nothing.

Senator PELL. That is it?

Mr. St. AMAND. That is it. We have people working in air pollution and things of that sort but there is no modification or any other use involved.

## PRODUCING ACIDIC RAINFALL

Senator PELL. Have you been able to develop a method of treating clouds with chemicals that could produce an acidic rainfall capable of fouling mechanical gear and equipment and radars and things of that sort?

Mr. St. AMAND. We haven't even thought of this.

Senator PELL. This is the first time you have thought of it?

Mr. St. AMAND. I read it in the newspapers but we haven't done anything at all like that.

Senator PELL. You have done no research along those lines?

Mr. St. AMAND. No; it would be grossly uneconomical anyway.

## SUIT AGAINST U.S. GOVERNMENT FOR PATENT INFRINGEMENT

Senator PELL. As you know, the U.S. Government is being sued for a patent infringement on its rights by a private contractor. Do you have any views with regard to the merits of his suit?

Mr. St. AMAND. This is a matter that is under litigation and it would be improper for me to discuss it but the Justice Department would probably be able to answer that question for you, sir.

Senator PELL. I thank you very much indeed. It is very good of you to be with us.

Thank you. The whole testimony will be in the record, as I say.

Mr. St. AMAND. Thank you, sir.

[Mr. St. Amand's prepared statement follows:]

## PREPARED STATEMENT OF PIERRE ST. AMAND, EARTH AND PLANETARY SCIENCES DIVISION, NAVAL WEAPONS CENTER, CHINA LAKE, CALIF.

Mr. Chairman, distinguished Senators and guests: My name is Pierre St. Amand. I live at 112 Blueridge, China Lake, California. I am employed at the Naval Weapons Center to direct work in environmental sciences. My background is that of a geologist-geophysicist with a broad interest in all aspects of earth science. I graduated from the University of Alaska and the California Institute of Technology. I was a Fulbright Research Scholar to France and I have worked with the International Cooperation Agency in South America. The main thrust of my professional work has been oriented toward the safe and profitable use of the environment for human benefit. You may find it odd that one interested in such things is employed at the Naval Weapons Center. The answer is that it has been the policy of the Navy to encourage and support science of use to the country as a whole as well as to the Navy itself. The opportunity to do good and useful work there is at least as great and probably greater than anywhere else in the Federal System.

I am appearing here at your invitation, not as a Navy representative but as a private citizen and as a scientist who has worked in the field of weather modification. Although I am proud to work with the Navy, and to some extent consider myself a part of it, some or all of my views may be at variance with those expressed by Officials of the Navy and of the Department of Defense. I am pleased to have the opportunity to express my own views on this important subject and to have them heard and considered.

The Navy has long had a tradition that good science of benefit to the nation and to humanity as a whole helps us all. Among the very first oceanographic efforts may be counted the works of Mathew Fontaine Maury. The massive compendium of navigational lore by Nathaniel Bowditch has been credited with the saving of millions of lives and having made navigation less hazardous than it was in the days before it was written. Astronomy as a whole has benefited from Navy interest in positional astronomy. Many advances in medicine and in other sciences have been supported by the Navy and this information has been shared with us all. It is not surprising therefore that the Navy, which has had to cope with the exigencies of the elements for its very survival at sea, should find weather modification a subject worthy of support. It is true that the Navy and the other armed forces stand to benefit from the science that they have developed. It is equally true that humanity at large has benefited from such work.

The story of our work at the Naval Weapons Center, formerly the Naval Ordnance Test Station, is an outgrowth of this policy. It was not a deliberate venture on the part of the Navy at the outset, but instead was the outcome of a concatenation of circumstances and abilities to be found at no other single place in the country. In 1957 Dr. William Finnegan and Dr. Lohr Burkardt of the Chemistry Division of the Research Department, were involved in the development of colored smokes that produced highly visible clouds to be used as markers at high altitudes. One of the techniques to produce such a smoke consisted in using lead iodate to oxidize an organic fuel so that lead iodide and free iodine were produced. This scheme resulted in a brilliant, reddish-violet smoke. Ancillary to this work they prepared a mixture that, upon combustion, produced silver iodide. They had heard of the use of silver iodide in cloud seeding, and living in an area where rain was a novelty, they were quite aware of the potential usefulness of their technique. They told me about it and we set about learning about cloud seeding.

As it turned out this approach was more important than we realized at first, because, theretofore, cloud seeders had been using a substance similar to, and derived from, silver iodide but which was not silver iodide. Silver iodide is used to cause supercooled water to freeze. If a substance is to catalyze the growth of ice, it must not dissolve in water before the water has time to freeze. Silver iodide is relatively insoluble, and because it has a molecular structure similar to that of ice, it is a good material to cause liquid water to freeze. In those days, clouds were seeded by use of an acetone burner that produced instead of silver iodide, a complex of silver iodide and one of several alkali iodides. It was not generally realized that the product of this device was not silver iodide but another compound quite different in its physical properties.

The exhaust products were water soluble and did not function as silver iodide was expected to do. This meant that people who were seeding clouds with the older system did not do what they thought they were doing. Indeed, in many elaborate experiments, based on the premise that clouds were being seeded with silver iodide, the clouds were not being seeded at all, or were being seeded in a manner different from that postulated. This single fact led to most of the confusion that has developed as to the effectiveness of cloud seeding, in that otherwise rigorously conducted experiments were producing indeterminate results. Most of the disagreement that is still to be found in academic circles is based upon this difference. The matter is now pretty well cleared up and the way is open to conduct a new set of efforts that could clearly demonstrate the effectiveness of cloud seeding under different meteorological conditions. Indeed, this is now being done by several agencies but at a level of support that is inadequate to the problem.

We soon became aware of this problem, and with the understanding that silver iodide could be produced in relatively pure form, in the right particle sizes and in the correct amounts, and that it could be emplaced in clouds at the right time, we went ahead and developed a cloud seeding system based on the use of pyrotechnics. We then tested a slightly different solution to be used in acetone burners that did indeed produce silver iodide. (This concept had been elucidated in 1949 by Dr. Bernard Vonnegut, the inventor of the acetone burner, but had been ignored.)

We were able to do this because the necessary talent for the research and development, indeed, a unique combination of chemists, physicists, engineers, pyrotechnic specialists, meteorologists and aviators, the necessary equipment and an enlightened management were all to be found in one place. A good deal of this work was supported by the Bureau of Reclamation and much of it was done in connection with the Department of Commerce for Project Stormfury.

The task of optimizing the system was lengthy. It was necessary to review, and in part correct, the theory of catalysis as applied to the freezing of water. We had to determine the correct particle size of the nucleant. We had to determine the right amounts. The solubility of silver iodide and other nucleants had to be considered and their rates of solution taken into account. New nucleating materials that worked at higher temperatures were developed. The materials and devices were tested in clouds over our ranges and over the southern Sierra Nevada. Samples of our seeding devices were sent to University groups and to other government agencies, so that tests might be conducted by others under realistic conditions.

For two years, we carried out experiments in the Southern Sierra for the Bureau of Reclamation. Later we cooperated with them in an effort conducted by Fresno State College, to increase the snow pack and the rainfall in the Central Sierra Nevada. For seven years we have been conducting, through a contractor, North American Weather Consultants, and with help from the Bureau of Reclamation, a rainfall augmentation experiment in the Santa Barbara area.

The work has gradually passed from experiments with single clouds to whole groups of clouds and to components of storm systems. No untoward incidents have occurred and none are expected because of the care with which we have set up the experiments to preclude excessive precipitation as a result of our efforts. We are now engaged in study of a technique for slowing down portions of winter storms and thus changing their trajectory so that the rain along the Pacific coast of California might be spread out a little more equitably thus reducing the perennial drought in Southern California and perhaps reducing the rain in the northern part of the state where it is usually too wet.

Part of our work has been dedicated to the modification of clouds too warm to be modified by the freezing process. For three years, we conducted experiments in the Brownsville, Texas area. This effort was intended to produce more rain from these marginal clouds and to suppress the growth of these clouds, should that prove desirable.

Fog clearance has received the lion's share of our attention in recent years because of the need to remove small patches of fog and to clear aircraft landing areas. The use of hygroscopic seeding agents was systematically tried and developed to the point where, under the conditions at Arcata, California, it is possible to produce instrument minimums in a 1,000-foot thick fog 80% of the time and to produce an actual opening about 60% of the time. The technique is expensive and messy but does work well enough to be used in emergency situations.

Recently we have begun an investigation of the use of electrically charged particles as fog clearing agents and are having promising results that indicate that it might be possible to clear fog with a greatly reduced logistic burden.

Prevention of fog formation by coating bodies of water with evaporation suppressants was tried with success in the Panama Canal. Improved methods of applying the evaporation suppressants have been developed by our Chemistry Division.

We have done limited work in fog formation and intensification. This system uses an aerosol consisting of common salt made more hygroscopic by the addition of small amounts of potassium and lithium chlorides. With these it is possible to create an overcast condition and to make small cumulus clouds under the right meteorological conditions. In the amounts needed to stabilize or to create fog, the materials are not toxic, are less corrosive than sea spray and far less harmful than conventional screening smokes.

The fog prevention work in Panama is being tested to see if it is possible to relieve the obstruction to navigation that occurs at night during the rainy season in the Gaillard Cut of the Panama Canal. If the tests being undertaken continue as well as they have, this method will prove useful in permitting uninterrupted flow of traffic through the canal, thus aiding world commerce. The techniques of applying the evaporation suppressants will no doubt become widely used commercially and will prove of benefit in applications where ranchers and others have, for a long time, used evaporation suppressants to conserve water in small reservoirs and stock ponds. Under extreme conditions of temperature and drought, such as are found in the arid southwest, this system can prevent the evaporation of from five to ten feet of water during a typical year. The materials are not ecologically harmful and offer no hazard to persons or animals.

On several occasions, the resources of the United States Military establishment have been called upon to take action against droughts in various parts of the world. In 1967, a small group of private contractors directed by the Naval Ordnance Test Station was sent to India to help with a devastating drought in the Bihar and Uttar Pradesh Provinces. Over a period of about three months, in the middle of the dry season about 100 clouds were seeded with air dropped pyrotechnic units. These clouds, most of which were not raining to begin with, yielded from  $\frac{1}{4}$  to  $\frac{1}{2}$  inch of rain. The drought was so far advanced, and the clouds so few, that this effort was not enough to materially affect the drought. It did show, however, that properly planned and conducted at the right time of the year, cloud seeding could beneficially aid that country in its agricultural efforts.

In 1969, a drought relief effort in the Philippines was conducted by the United States, using Air Force aircraft and crews and technical personnel from the Naval Weapons Center. This effort was remarkably successful, because clouds, that were in general too small to rain by themselves, were caused to grow and rain abundantly. It was estimated by the Philippine government that at least \$60,000,000 in additional foreign exchange was developed by agricultural use of the rain resulting from the cloud seeding. In addition, another \$25,000,000 was saved because it was not necessary to import corn and rice. The following year, the Philippine Sugar Institute led an effort using a United States contractor and Philippine pilots who had been trained the previous season by our personnel. This effort met with the same sort of success and the capability to seed clouds has been retained and augmented. It was not necessary to use it in 1971 and 1972, but some work was done in 1973 and it appears that the Filipinos will continue to make wise use of the capability as it is needed.

In 1971, we were called upon to help the Island of Okinawa, then under U.S. military control. A protracted drought had reduced the water shortage on the Island to inadequate proportions and the populace was subjected to severe water rationing. The Islands had about a million people trying to use the water falling on the approximately 600 square miles of land available, most of which drains directly into the sea. The United States Navy made available the services of the anti-submarine patrol squadron at Naha and we furnished technical direction for a period of a few weeks. Here, the skills developed by the patrol squadron in tracking ships and submarines made it an easy matter to select clouds at sea whose trajectory would lead them over land and to estimate the time of landfall of the cloud. The clouds so selected were seeded at sea, caused to grow and kept alive until they came within 10 minutes of landfall, at which time they were seeded for maximum growth, and in the course of blowing across the Island, beneficial amounts of rainfall were produced. The task was doubly difficult because it was necessary to avoid having rain on certain parts of the island at some times. In spite of the difficulties, and because of the skill of the Patrol Squadron, it was possible to increase the rainfall to the point where water rationing could be suspended. The work started in July and was terminated in December, when enough typhoons passed by to assure the island of an adequate water supply for the time being. In addition, most of the rest of the Ryukuan Islands were also artificially irrigated during the expedition.

In 1971, Air Force crews that had been trained in the Philippines, were called upon for a short time to relieve a drought in Texas. Once again, NWC furnished seeding materials and equipment and aided in the training of the aircrews, but did not participate directly in the effort. After a short time, the Air Force withdrew and commercial operators were called upon to take over the work.

In 1972, the Naval Weapons Center and the Hurricane Hunter Squadron, VW-4, were asked to help with a drought in the Azores. With one weather reconnaissance aircraft, technical advice from NWC and help from the Air Weather Service, it was possible to wet down all of the islands in the Azores several times. After two weeks, the weather reconnaissance aircraft was replaced by aircraft from the local patrol squadron and the work continued until the drought situation had passed. Once again, the skill of the Navy crews in tracking clouds made possible a successful effort that would have been extremely difficult, if not impossible, otherwise.

It would have been possible, and still is possible, to apply these techniques in many parts of the world where life itself depends on additional rainfall. It appears that this practice has been stopped and the good precedent dropped. The reason is not clear, for the efforts were effective and no untoward incidents, such as excessive rainfall, occurred.

The seeding techniques that we have in large part developed are now in use in almost every country in the world. The devices that we developed for seeding are widely copied and manufactured. We have made such information as we had freely available to people here, and abroad, who chose to carry on development on their own. In connection with rainfall augmentation we have worked with or advised the following groups of people and domestic agencies.

Department of the Interior, Bureau of Reclamation

Department of Commerce; Stormfury Project, Great Lakes Project, Florida

Cumulus Project

National Committee on Atmospheric Research; Hail Projects

Department of Agriculture

State of South Dakota

U.S. Forest Service

State of Washington

State of California

South Dakota School of Mines and Technology

Colorado State University

University of Montana

University of Washington

University of Wyoming

Numerous private corporations

We have had contact with individuals interested in this matter in the following countries: India, Philippines, Taiwan, Chile, Israel, Rhodesia, Mexico, Portugal, England, France, Italy, Argentina and Australia.

A substantial portion of the critical scientific theory was developed at NWC. Our contributions include clarification of nucleation theory for the formation of ice in clouds, solution of Smoluchowski's equation in general form. Methods for calculation of the time required for a solid of a given size to dissolve in a solvent were developed. Improved values of collection coefficients were calculated. Theory applying to the use of electrically charged particles to capture other particles was extended. The theory of condensation was improved. A number of new nucleating compounds were developed, for use at temperatures warmer than that at which silver iodide functions, and were tested. Improved acetone burners for ground based and for airborne use were developed.

It has been suggested that control of the environment would constitute a truly horrible weapon of war. If all the things that the proponents of restricting the use of geophysical weapons imagine could be done were doable, this might be true. As it is, one can only make rain, clear fog and reduce hail at the present time. On a tactical scale, this technology could be very useful to the United States and would not constitute a threat to the climate of the world. The potential exists that over the years, the applications of geophysics to warfare could become a very important military tool.

No one can, at present, influence earthquakes in any appreciable way. It is true that small earthquakes have occurred as reservoirs were being filled and in a few instances appear to have been caused by underground pumping. These techniques hold no promise for any deliberate use in controlling such phenomena, nor can I envision any techniques for producing or influencing earthquakes one way or the other. By understanding the nature and mode of occurrence of earthquakes and the application of sound engineering and good construction practices, the threat of earthquakes can in a few tens of years be abated.

Tsunamis are caused by large earthquakes. There is no way to produce true tsunamis. Even if there were, a tsunami would not affect installations more than a few hundred yards of the shoreline. Tsunamis would not be a useful weapon because they radiate over the whole ocean and would cause extensive damage to friendly coasts as well.

Changes in ocean currents are possible to attain with protean efforts. One could perhaps dam the Bering Straits or divert the Gulf Stream. Such an effort would require the cooperation of a large part of the world and would present such unforeseen consequences that it is unlikely that it would, or could, be done unilaterally by any civilized nation.

I, therefore, feel that such a treaty addresses things that cannot be done now, are extremely unlikely in the next century, and probably wouldn't be done in any case and is therefore premature.

A treaty to preclude generic use of geophysical weaponry as could be used to cause damage in excess of that necessary for the attainment of the objective is not needed, because we are already morally and, in effect, legally bound to do as



the treaty would say. We would, if no such treaty existed, not be bound to forego the use of an advantageous system were that system to be used effectively in the protection of our own forces, people and property. One must consider in proposing such a treaty, whether the use of any weapon or device whatsoever to protect a fighting force does in itself constitute an act of war.

To my mind anyone who does anything in support of his government, or economy, in a time of war is a member of the fighting team and is participating in war. If this be so, how can we distinguish when an act is performed if it will be in violation of the treaty? The complete barrier to all such work as proposed in the treaty could moreover work unnecessary hardship on our defense forces. For example: Would it be proper to clear fog so that our war planes could safely return from combat? Would it be proper to clear fog so that they could launch a mission? Would it be proper to clear a target area so that they could strike the enemy? All of these would appear to be proscribed. It might also be improper to clear fog for any purpose whatsoever, if the persons whose work was facilitated by such clearance could more effectively aid the military effort of their country.

Some distinction should be made that is not now made in the proposed treaty, or the United States may have to deprive itself from the enjoyment of such advantages as might flow from peaceful use of weather modification, if it were done in time of war, to augment food or energy supplies so that the war could be more effectively fought.

Weather is a terrible problem to the Navy and to a lesser extent the Air Force. To the Army and the Marines the weather is a serious factor that must always be contended with and which often decides the outcome of military contests. There are situations wherein the technology would not be used in actual combat to hurt the enemy but might greatly aid our own troops while engaged in a war. Excessive fog could prevent resupply as it did in the Battle of the Bulge. The American troops were short on food, ammunition and fuel and were unable to advance. This advance was critical to obtaining the fall of Germany while the Wehrmacht was still reeling from earlier reverses. A portion of the time, this fog was supercooled. Available techniques can now, with a very high reliability, clear supercooled fog in a matter of 30 or 40 minutes. It would have shortened World War II by several weeks if the technology had then been available. Would it have been wrong to use the technology? I think not.

Tank and infantry warfare is dependent upon a fairly hard surface for the mobility of troops and equipment. Were a situation to arise in which by increasing rainfall, one could decrease the trafficability to such a point that the efforts of the enemy to attain an objective were thwarted or delayed until we could prepare for a confrontation, would we be justified in using weather modification? I think so.

On the other hand, if there were no clearcut military target and the only outcome of one's action were to cause misery for the civilian population, and there were other ways of preventing men and material from reaching the front, then the use of such tactics would clearly be irresponsible in that damage would be caused without gaining any real advantage for oneself.

Force should be limited to that necessary to obtain the objective. It is equally true that to use less force than necessary is wrong in that it prolongs the conflict and in the end causes more loss of life, suffering and property damage and incurs the risk of losing. The use of force must be delicately balanced; to use too much is irresponsible, to use too little is wrong. We should reserve to our fighting forces, and to our Commander in Chief, the right to make such use as is necessary of such tactical weapons as they may need to win a war in which we might be engaged; or at least, to keep the war going at a controlled level until such time as they have, by other means, obtained the objectives of the confrontation.

One must also address the question of whether or not geophysical warfare would constitute cruelty. All war is bad and counterproductive. Usually wars are fought with high explosives, projectiles and other products that have a deleterious effect on personnel. Would it be less cruel to immobilize an infantry company with excessive rainfall than it would be to burn them with Napalm or destroy them with bombs? If they would be kept out of the fight and not be permitted to hurt themselves or others, would it not be better than killing them? These people will certainly come in handy during the reconstruction when the damage caused by conventional weapons must be repaired and their country rebuilt.

Another type of geophysical warfare that has two sides to it might be the manufacture of a long term change in climate. Two sides, because it could be used to harm or to aid a potential enemy. Assume for the minute that a large country exists in which a non-irrigable crop must be planted and matured so that the coun-

try has adequate food and foreign exchange. It might, to take a negative viewpoint, be advantageous to cause heavy rain during planting season to preclude sprouting and growth and then to cause severe and protracted drought during the growing season. This could conceivably cause a crop failure and bring our hypothetical enemy to his economic knees. First we would have to be able to do it and we now cannot. Secondly, we would have to get them to hold still for it—this might not be possible. Thirdly, world opinion, if the effort were discovered, and it almost certainly would be, would force the aggressor to desist, perhaps too late for that season, but the impact of world opinion might be such as to make such action unprofitable.

On the other hand, it might just be possible to benefice the climate of the place to the point where the potential enemy could have such an adequate economic base that he would have too much to lose by engaging in war. Let us assume that a large country was, because of overpopulation, poor soils and protracted drought, in such a position that it was a wasteland populated by starving hordes. With what is now known in agriculture, land management, water management and weather modification, it might well be possible to help that country obtain a viable economic status and supply its own needs. In the end, this might well result in improved world relations. Whether to do this or not is a matter for that country involved to decide. On the other hand we might wish to help them. With their consent and cooperation one might call upon U.S. military forces to undertake a large share of the weather modification work because they would have the capability and equipment to do so. The trained and disciplined personnel could do it more capably than an ad hoc collection of resources. Thus the military could be used constructively in foreign affairs, doing the very things that the proposed treaty would not let them prepare for. In a well run country, the armed forces are a tool of the makers of foreign policy; we should keep this tool sharp and available.

I should now like to address another aspect of such a treaty. Would small scale violations be detectable? Would the treaty be enforceable? The answer to both questions is in doubt at the present time. Unless adequate intelligence were available so that we could learn of the preparations and plans for such an adventure it is unlikely that a violation could be detected until it was too late. There is now no way to tell if a storm has been seeded. It is true that the seeding agent might possibly be detected and identified. With what technology now exists, it is extremely difficult to do so because the air all over the world is so polluted by heavy metals that the augmentation of heavy metal content of rain caused by cloud seeding could not be told from that already present. The science of weather prediction is not yet so exact that small changes produced by weather modification could be detected. Were such changes on a subcontinental scale they would probably attract attention.

Were they to attract attention we should be faced with the problem of calling the malefactors on it. Would this be settled easily by diplomatic negotiation or would we be obligated to make them quit?

In order to prevent violation of such a treaty, we would have to spend a fortune finding means of detecting such activity and proving that the treaty was not being obeyed. An example comes to mind in the field of seismology, where in order to detect violations of a treaty involving testing of nuclear weapons, millions of dollars were spent developing a seismic detection system. The technology developed to detect atomic explosions is in part applicable to earthquake work but the science of seismology dedicated to study of earthquakes received much less attention, and still does to a very large extent, in spite of the fact that a large earthquake anywhere in the country would be a civic and economic disaster of outrageous proportions.

In closing, I would like to thank you for the chance to make my ideas known and to acquaint you with the work of my organization. I feel that the things we have done have been good and have been a worthwhile expenditure of the government's money and our time. That we are in a Navy laboratory has facilitated the work we have done and I really feel that it probably would not have been done as soon had not the Naval Ordnance Test Station decided to go ahead in a new field that at the time was clearly of more general and humanitarian interest than military utility. Eventually, others would have done the same things and perhaps done them better. We have, however, been a force in shaping the direction in which weather modification in this country has gone and I believe that it was a good direction. It has been a pleasure for us to work with the other federal agencies in the development of their own programs, to use the things they turned out and to see them use ours. I believe you will agree with me that the humanitarian uses of the things we have done in a Naval Laboratory have been worthwhile.

Let me say that if we must have a treaty, let us write another one eschewing all forms of violence as a means of settling disputes. If we can't do that, and if we must have the proposed treaty, let us so write it that:

(1) Tactical use of geophysical weapons be permitted for the benefit and protection of our fighting forces.

(2) Strategic use be limited, when and if it becomes a reality, to peaceful application by mutual agreement of the countries concerned and the concurrence of such neighbors as may also be affected.

(3) That military forces be used in such constructive efforts if it is to advantage to do so.

Thank you.

Senator PELL. Our next witness is Dr. Gordon MacDonald, the Henry Luce Professor of Environmental Policy and Study of Dartmouth College, a former member of the Council on Environmental Quality, and I must say he looks much more refreshed and invigorated and younger than when I last saw him.

### STATEMENT OF DR. GORDON J. F. MacDONALD, DARTMOUTH COLLEGE, HANOVER, N.H.

MR. MACDONALD. University life today is far different than it was a few years ago and certainly much more pleasant than life in Government, I can assure you.

#### NEED FOR INTERNATIONAL AGREEMENT

I welcome this opportunity to discuss with you certain aspects of weather modification and in particular the need for an international agreement prohibiting the use of weather modification as a weapon of war.

The action taken by the Senate on July 11, 1973, passing Senate Resolution 71, was a much-needed first step toward achieving such an agreement. It is in my view most unfortunate that the administration has not sought to initiate those steps required to implement the resolution.

#### INDICATIONS UNITED STATES WOULD BE JOINED BY OTHER COUNTRIES

I believe the time is particularly appropriate for the United States to take a new initiative in this area. A number of contacts over the past year have convinced me that we would be joined in this undertaking by a large number of countries, including the U.S.S.R.

One example where such contacts were made was the VII Dartmouth Conference. This unofficial meeting was held during the week of December 3, 1972, and a number of high-level Soviet officials participated. The Soviet co-chairmen were E. K. Federov, a member of the U.S.S.R. Academy of Sciences and Chief of the Main Directorate of the Hydrometeorological Service of the U.S.S.R., and G. A. Zhukof, Pravda commentator and Deputy to the Supreme Soviet of the U.S.S.R.

The U.S. delegation included a number of your colleagues from the other House, William Ruckelshaus, then Administrator of the Environmental Protection Agency but not acting in his official capacity, and a group of distinguished private citizens from the industrial,

financial, and scientific worlds. The joint communique makes specific reference to geophysical warfare and I quote from the communique:

The participants in this meeting completely reject the use of chemical, biological, or nuclear means of mass destruction. They also reject attempts to make use of man-made environmental change as a means of waging war, and urge that an international agreement be sought renouncing the development and use of such weapons.

This, I believe, is a strong endorsement of the principles contained in Senate Resolution 71. Since that meeting I have on several occasions met with Soviet Academician Federov and am certain that he holds today the views expressed in that communique of over a year ago.

Senator PELL. I must add I raised this question also with Mr. Brezhnev when we had our meeting at the Blair House. He did not make any substantive reply but it is a subject I am glad that you did discuss with the Soviets.

Mr. MACDONALD. My last meetings with Academician Federov were at the end of June, and then again early this fall when he was here chairing the Soviet delegation on the United States-U.S.S.R. Environmental Agreement. On both occasions he expressed the views to which I have referred.

In view of these informal contacts and others, it would seem a most propitious time for the United States, together with other nations, to advance a treaty much along the lines of that contained within Senate Resolution 71.

#### ROUTES TO ACHIEVING TREATY

A number of routes could be followed to achieve such a treaty. For example, action could be initiated through a U.N. resolution such as has been passed on other arms control issues. Alternatively, the United States and U.S.S.R. could call a conference under U.N. auspices to negotiate the details of the treaty. Or the latter course could follow on the passage of an appropriate U.N. resolution.

#### REASONS TO SEEK UNIVERSAL BAN

There are a number of reasons to seek a universal ban on this new method of warfare. While these reasons have been discussed in detail in previous hearings, I believe it important to reiterate them.

Science and engineering of weather modification have not advanced to such an extent that all effects are predictable. Actions, such as rainmaking, which are taken to achieve a localized advantage, may have far-reaching and unforeseen effects.

Second, weather modification, whether it is simple rainmaking or the much more complex and poorly understood steering of storms or disbursing climates, would certainly involve civilians and nonmilitary facilities in addition to the presumed military targets.

The generally accepted, although often violated, rules of war prohibit making civilians an avowed or obvious object of an attack.

A third and very significant point is that the widespread acceptance of techniques of geophysical warfare as legitimate would further blur the distinction between conventional and unconventional means of warfare.

Deficiencies both in the basic understanding of the physical processes of the environment and the technology of environmental change, to which I have referred, make it highly unlikely that environmental modification will be an attractive weapon system in any direct military confrontation, at least in the near future.

Man already possesses highly effective tools to achieve destruction. Eventually, however, means other than open warfare may be used to secure national advantage. Widespread, unconventional guerrilla attacks such as we have witnessed over the past few years illustrate how the definition of war is changing. As economic competition among many advanced nations heightens, it may be to a country's advantage to insure a peaceful, natural environment for itself and a disturbed environment for its competitors.

Operations producing such conditions might be carried out covertly since nature's great irregularities permit storms, floods, droughts, earthquakes, and tidal waves to be viewed as unusual but not unexpected. Such a secret war need never be declared or known by the affected populations. It could go on for years with only the security forces involved being aware of it. The years of drought and storm could be attributed to unkindly nature and only after a nation was thoroughly drained would an armed takeover be attempted.

Finally, even the possibility that nation-states might view environmental modification as a weapon of war casts suspicion on the legitimate development and use of environmental modification for peaceful and beneficial purposes.

Indeed, the appearance that a country or countries are undertaking research that could lead to weapons of war might very well lead to the breakdown of the century-old tradition and practice of sharing meteorological data. Through agreements between nations and through the activities of the World Meteorological Organization, a specialized United Nations' agency, virtually all countries of the world freely exchange atmospheric data. This makes it possible for the weather services of individual nations to provide the much needed forecasts.

If the United States were to be cut off from observations taken by other nations, particularly from those in the northern hemisphere, there would be severe economic consequences, the magnitude of which is difficult to estimate.

#### JUSTIFICATION FOR INTERNATIONAL DISCUSSIONS OF WEATHER MODIFICATIONS

In addition to reasons directly connected with warfare, I believe international discussions of weather modifications are justified in two other important ways.

Today countries are undertaking weather modification operations as opposed to experiments. The issue may well arise as to whether or not such operations are advantageous or disadvantageous to neighboring countries.

Seeding in the high Cascades in order to increase snowpack may be perceived by our Canadian neighbors as possibly affecting their weather or climate. You can imagine countless other scenarios in which activities in one country might possibly affect the environment in another.

Unless satisfactory international instruments exist, misunderstandings and tensions could arise.

Second, certain proposed weather modification experiments such as a continuation of Project Stormfury in the Pacific would require the cooperative efforts of several countries. Again, early discussions among countries which could possibly be affected by such operations, or discussions with other countries that would wish to participate in the development of that technology, would be of great assistance in carrying such programs forward.

#### QUESTIONS RAISED BY SENATE RESOLUTION 71

Senate Resolution 71 does raise a number of questions. For example, it is likely to generate controversy over whether the ban on the use of weather modification should cover fog dispersal. Fog dispersal can and has been used to permit landings and takeoffs of warplanes under conditions where such operations would not be possible.

From time to time, there have been comments in the press that the United States has used fog dispersal to rescue downed pilots during the Vietnamese conflict. There are those who would argue that the use of fog dispersal opens up the possibility for the use of more damaging techniques.

I would argue for the opposite view, primarily because many of the techniques for fog dispersal are dissimilar to those used to enhance precipitation or bring about other changes in weather. For example, the use of propane for cold fog dispersal and the use of other chemical agents for warm fog dispersal is quite unlike the use of silver iodide in increasing rainfall.

A second problem is the ever-present question of verification. Certainly, weather modification experiments on a small scale can be carried out covertly. However, even on a relatively small scale, a cloud-seeding experiment might be detected at distances as great as 100 kilometers or so because extremely sensitive techniques have been developed that could measure fluctuations in silver content of rain or air.

Furthermore, acceptable arms control agreements do not require the ability to detect every violation—only major ones. A variety of techniques, including currently accepted national techniques of verification, could be applied to determine whether or not a nation has underway a covert weather or climate modification research and development program.

In moving toward such a treaty as advocated by the Senate, we should remember that the political, legal, economic, and sociological consequences of deliberate environmental modification, even for peaceful purposes, will be of such complexity that perhaps all our present involvement in nuclear affairs will seem simple by comparison.

Our understanding of basic environmental science and technology is primitive. Still more primitive are our notions of the proper political forms and procedures to deal with consequences of modification.

The experiences before and at the Stockholm U.N. Conference on the Human Environment demonstrated the problems of dealing with inadvertent modification of the environment. All experience shows that less significant technological changes than purposeful environmental control finally transform political and social relationships. Experience

also shows that these transformations are not necessarily predictable and that the guesses we might make now based on precedent are likely to be wrong.

It would seem, however, that these nonscientific, nontechnological problems are of such magnitude that they deserve consideration by nations throughout the world if society is to live comfortably in a more controlled environment.

#### SENATE RESOLUTION 71 IMPORTANT CONTRIBUTION

It is in this sense that I believe Senate Resolution 71 is such an important contribution to that goal. I strongly hope that these hearings provide the necessary encouragement for the administration to proceed in a major diplomatic effort to bring about a treaty banning the use of methods of environmental modification for hostile purposes.

Thank you, Mr. Chairman, and I would be glad to respond to any questions.

Senator PELL. Thank you very much, indeed.

#### SENATE PASSED SENATE RESOLUTION 71 BY 82 TO 10

Apropos the support for the Senate resolution, I think it should be borne in mind that the administration is opposed, as we both know, to the enactment of it and had an ample chance to make its views known to the Foreign Relations Committee and to the Senate. There was substantial debate in which the administration made its contribution, and yet the Senate, which is not a stupid body, after actually considering the pros and cons of it, as sensible men, some wearing the American flag in their buttonholes, others just as good Americans not wearing the flag in the buttonhole, together collectively we decided 82 to 10 that we should move ahead in this direction. That is a pretty good jury and pretty good decision when you have exposure to both sides and both viewpoints.

#### POTENTIAL ENVIRONMENTAL AND GEOPHYSICAL WEAPONS

I was wondering if you would give us a little laundry list, check them off, one, two, three, four, five, of what are potential environmental and geophysical weapons. I remember reading an article you wrote that had such a laundry list, and I was wondering if you would refresh my memory with that list and if there had been any additional weapons added in.

Mr. MACDONALD. We could certainly start with modification of precipitation. I think the enhancement of precipitation is a technology that is at hand, and we can use it today if we so wish for practical purposes. Whether or not it could be used over a long term for strategic purposes is a matter of debate.

Unlike the previous witness, I do believe that there have been advances in the understanding of the mechanics as to how earthquakes come about, how earthquakes might be initiated, and how they might be avoided.

The experience in the Rocky Mountain Arsenal, in which fluids were injected, demonstrates how man can trigger earthquakes. Experiences with the Rasilliston experiment further demonstrate a very close connection with fluid injection and the setting off of earthquakes.

I believe that, once we achieve this better understanding of earthquake, it would be possible to generate large tsunami waves that could be used as weapons of war. We have a much better understanding of the high atmosphere and of the role that the very important molecule ozone plays in the high atmosphere.

I can imagine ways that we could remove the compound from the atmosphere, increase the intensity of ultraviolet radiation, and through covert means select the parts of the world where enhanced ultraviolet radiation would have adverse effects on all biological life.

In fact, I think if you look at any aspect of the environment anywhere, you can see we are beginning to develop a technology that can influence that part of the environment. You have a potential weapon of war, and that is why I think it is so important to stop right now before those technologies develop. They are not developed now except to the limited extent of precipitation modification.

If we agree on an international basis, however, that we should not go ahead and develop these techniques for hostile purposes, then I think we have made an enormous advance.

Senator PELL. To add to your laundry list of potential weapons, you would also have the melting of icecaps. What other ones might you be able to tick off as being possible development in the future?

Mr. MACDONALD. I think the icecap potentially could bring about worldwide changes of climate. Another possibility is to melt the bottom of the Antarctic icecap and cause tidal waves of one sort or another by having the ice slide more rapidly out into the ocean than it otherwise would by providing a heat source at the bottom of the ice.

One can imagine certain kinds of modifications of the electrical behavior of the atmosphere that might possibly influence the activities of individuals through interaction with what is called the alpha activity of the brain.

There are just countless examples, as you said, a laundry list. I give you five or six kinds of ways one can think but basically what I am saying is that any time you alter the environment, whether it be air, water, or the electric magnetic conditions under which you live, you have a potential weapon.

#### WITNESS' ARTICLE

Senator PELL. Without objection, I shall insert in the record the article that you wrote, of which maybe you would send us an extra copy.

Mr. MACDONALD. I would be delighted to do so. This goes back to 1966.

[The information referred to follows:]

[From "Unless Peace Comes," Nigel Calder, Ed., The Viking Press, N.Y., 1968]:

#### How To WRECK THE ENVIRONMENT

(By Gordon J. F. MacDonald, United States)

Professor MacDonald is associate director of the Institute of Geophysics and Planetary Physics at the University of California, Los Angeles. His researches have embraced a remarkable diversity of natural phenomena, and his professional interests are further extended by his participation in national science policy-making. He is a member of President Johnson's Science Advisory Committee.



Among future means of obtaining national objectives by force, one possibility hinges on man's ability to control and manipulate the environment of his planet. When achieved, this power over his environment will provide man with a new force capable of doing great and indiscriminate damage. Our present primitive understanding of deliberate environmental change makes it difficult to imagine a world in which geophysical warfare is practiced. Such a world might be one in which nuclear weapons were effectively banned and the weapons of mass destruction were those of environmental catastrophe. Alternatively, I can envisage a world of nuclear stability resulting from parity in such weapons, rendered unstable by the development by one nation of an advanced technology capable of modifying the earth's environment. Or geophysical weapons may be part of each nation's armory. As I will argue, these weapons are peculiarly suited for covert or secret wars.

Science-fiction literature contains many suggestions of how wars would progress if man indeed possessed the ability to change weather, climate, or ocean currents. Many of these fictional suggestions, and other more serious discussions, fail to take into account the limitations of nature. Jules Verne gave a detailed discussion of displacing the earth's polar caps, thus making the world's climatic zones more equitable (*Les Voyages Extraordinaires; Sans Dessus Dessous*, Metzel, 1889). Verne's proposal was to eliminate the twenty-three-degree tilt in the earth's axis, putting it at right angles to the sun-earth plane. However, as Verne correctly pointed out in a subsequent discussion, the earth's equatorial bulge stabilizes our planet, and even the launching of a 180,000-ton projectile would produce a displacement of only one-tenth of a micron. Senator Estes Kefauver, Vice-Presidential candidate in the 1956 American election, rediscovered Verne's original proposal and was seriously concerned with the tipping of the earth's axis. He reported that the earth's axis could, as the result of an H-bomb explosion, be displaced by ten degrees. Either Senator Kefauver or his scientific advisers neglected the stabilizing influence of the earth's bulge. The maximum displacement that can be expected from the explosion of a one-hundred-megaton H-weapon is less than one micron, as Walter Munk and I pointed out in our book, *Rotation of the Earth* (Cambridge University Press, New York, 1960).

Substantial progress within the environmental sciences is slowly overcoming the gap between fact and fiction regarding manipulations of the earth's physical environment. As these manipulations become possible, history shows that attempts may be made to use them in support of national ambitions. To consider the consequences of environmental modification in struggles among nations, we need to consider the present state of the subject and how postulated developments in the field could lead, ten to fifty years from now, to weapons systems that would use nature in new and perhaps unexpected ways.

The key to geophysical warfare is the identification of the environmental instabilities to which the addition of a small amount of energy would release vastly greater amounts of energy. Environmental instability is a situation in which nature has stored energy in some part of the earth or its surroundings far in excess of that which is usual. To trigger this instability the required energy might be introduced violently by explosions or gently by small bits of material able to induce rapid changes by acting as catalysts or nucleating agents. The mechanism for energy storage might be the accumulation of strain over hundreds of millions of years in the solid earth, or the supercooling of water vapor in the atmosphere by updrafts taking place over a few tens of minutes. Effects of releasing this energy could be worldwide, as in the case of altering climate, or regional, as in the case of locally excited earthquakes or enhanced precipitation.

#### WEATHER MODIFICATION

The earth's atmosphere is an envelope of air that rotates, for the most part, at the same speed as the underlying continents and oceans. The relative motion between the atmosphere and the earth arises from sources and sinks of energy that vary in location and strength but which have, as their ultimate source, the sun's radiation. The quantities of energy involved in weather systems exceed by a substantial margin the quantity of energy under man's direct control. For instance, the typical amount of energy expended in a single tornado funnel is equivalent to about fifty kilotons of explosives; a single thunderstorm tower exchanges about ten times this much energy during its lifetime; an Atlantic hurricane of moderate size may draw from the sea more than 1000 megatons of energy. These vast quantities of energy make it unlikely that brute-force techniques will lead to sensible weather modification. Results could be achieved, however, by working on the instabilities in the atmosphere.

We are now beginning to understand several kinds of instabilities in the atmosphere. Supercooled water droplets in cold clouds are unstable, but they remain liquid for substantial periods of time unless supplied with nuclei on which they can freeze. Conversion of water droplets to ice through the introduction of artificial nuclei can provide a local source of energy. This released heat can cause rising air currents, which in turn lead to further formation of supercooled water. This process may lead to rainfall at the ground greater than that which would have been produced without the artificial nucleation. A second instability may arise, in which water vapor condenses into water, again affecting the distribution of sensible energy. On a larger scale, there is the so-called baroclinic instability of atmospheric waves that girdle the planet. Through the imbalance of heat between equator and pole, energy in this instability is stored, to be released in the creation of large cyclonic storms in the temperate zones. There are other, less well understood instabilities capable of affecting climate, I shall return to them later.

What is the present situation with respect to weather modification and what might be reasonably expected in the future? Experiments over the past eighteen years have demonstrated unequivocally that clouds composed of supercooled water droplets can be transformed into ice-crystal clouds by seeding them with silver iodide, "dry ice" (frozen carbon dioxide), and other suitable chemical agents. This discovery has been applied operationally in the clearance of airports covered by supercooled ground fog. No analogous technique has yet evolved for clearing warm fog, although several promising leads are now being investigated. In the case of warm fog, the atmospheric instability is that water vapor distributed in small drops contains more surface energy than the same water distributed in large drops. The trick for clearance of this warm fog will be to discover some way of getting the small drops to organize themselves into larger ones and then fall to the ground.

There is increasing, though inconclusive, evidence that rainfall from some types of clouds and storm systems in temperate regions can be increased by ten to fifteen per cent by seeding. Somewhat more controversial evidence indicates that precipitation can be increased from tropical cumulus by techniques similar to those employed in temperate regions. Preliminary experiments on hurricanes have the aim of dissipating the clouds surrounding the eye of the storm in order to spread the energy of the hurricane and reduce its force. The results are controversial but indicate that seeding can, in certain circumstances, lead to a marked growth in the seeded cloud. This possibility may have merit in hurricane modification, but experimentation has not yet resulted in a definitive statement.

Regarding the suppression of lightning there is mixed but largely promising evidence that the frequency of cloud-to-ground strokes can be reduced by the introduction of "chaff" strips of metallic foil of the kind used for creating spurious echoes in enemy radars.

In looking to the future, it is quite clear that substantial advances will be made in all of these areas of weather modification. Today, both military and civilian air transport benefit from progress in the clearance of ground fog. Further progress in the technology of introducing the seeding agent into the fog makes it likely that this type of fog dispersal will become routine. In a sense, fog clearing is the first military application of deliberate manipulation of weather, but it is, of course, very limited.

Large field programs are being undertaken in the United States to explore further the possibility of enhancing precipitation, particularly in the western and northeastern states. On the high ground of the western states, snow from winter storms provides much of the country's moisture. Investigations are under way to see if seeding can lead to an increased snowpack and thus enhance the water resources. Intense interest in this form of weather modification, coupled with an increased investigation of the physics of clouds, is likely to lead to effective cloud modification within the next five to fifteen years. At present the effects are measured only statistically, and too little has been done in cloud observation before and after seeding in the way of precisely pinpointing which clouds are most likely to be affected.

As far as military applications are concerned, I conjecture that precipitation enhancement would have a limited value in classical tactical situations, and then only in the future when controls are more thoroughly understood. One could, for example, imagine field commanders calling for local enhancement of precipitation to cover or impede various ground operations. An alternative use of cloud seeding might be applied strategically. We are presently uncertain about the effect of seeding on precipitation down wind from the seeded clouds. Preliminary analysis suggests that there is no effect 200-300 miles down wind, but that continued seeding over a long stretch of dry land clearly could remove sufficient moisture to pre-

vent rain 1000 miles down wind. This extended effect leads to the possibility of covertly removing moisture from the atmosphere so that a nation dependent on water vapor crossing a competitor country could be subjected to years of drought. The operation could be concealed by the statistical irregularity of the atmosphere. A nation possessing superior technology in environmental manipulation could damage an adversary without revealing its intent.

Modification of storms, too, could have major strategic implications. As I have mentioned, preliminary experiments have been carried out on the seeding of hurricanes. The dynamics of hurricanes and the mechanism by which energy is transferred from the ocean into the atmosphere supporting the hurricane are poorly understood. Yet various schemes for both dissipation and steering can be imagined. Although hurricanes originate in tropical regions, they can travel into temperate latitudes, as the residents of New England know only too well. A controlled hurricane could be used as a weapon to terrorize opponents over substantial parts of the populated world.

It is generally supposed that a hurricane draws most of its energy from the sea over which it passes. The necessary process of heat transfer depends on wave action that permits the air to come in contact with a volume of water. This interaction between the air and water also stirs the upper layers of the atmosphere and permits the hurricane to draw on a substantially larger reservoir of heat than just the warm surface water. There may be ways, using monomolecular films of materials like those developed for covering reservoirs to reduce evaporation, for decreasing the local interaction between sea and air and thus preventing the ocean from providing energy to the hurricane in an accelerated fashion. Such a procedure, coupled with selective seeding, might provide hurricane guidance mechanisms. At present we are a long way from having the basic data and understanding necessary to carry out such experiments; nevertheless, the long-term possibility of developing and applying such techniques under the cover of nature's irregularities presents a disquieting prospect.

#### CLIMATE MODIFICATION

In considering whether or not climate modification is possible, it is useful to examine climate variations under natural conditions. Firm geological evidence exists of a long sequence of Ice Ages, in the relatively recent past, which shows that the world's climate has been in a state of slow evolution. There is also good geological, archeological, and historical evidence for a pattern of smaller, more rapid fluctuations superimposed on the slow evolutionary change. For example, in Europe the climate of the early period following the last Ice Age was continental, with hot summers and cold winters. In the sixth millennium B.C., there was a change to a warm humid climate with a mean temperature of five degrees Fahrenheit higher than at present and a heavy rainfall that caused considerable growth of peat. This period, known as a climatic optimum, was accentuated in Scandinavia by a land subsidence that permitted a greater influx of warm Atlantic water into the large Baltic Sea.

The climatic optimum was peculiar. While on the whole there was a very gradual decrease of rainfall, the decrease was interrupted by long droughts during which the surface peat dried. This fluctuation occurred several times, the main dry periods being from 2000 to 1900, 1200 to 1000, and 700 to 500 B.C. The last, a dry heat wave lasting approximately 200 years, was the best developed. The drought, though not sufficiently intense to interrupt the steady development of forests, did cause extensive migrations of peoples from drier to wetter regions.

A change to colder and wetter conditions occurred in Europe about 500 B.C. and was by far the greatest and most abrupt alteration in climate since the end of the last Ice Age. It had a catastrophic effect on the early civilization of Europe: large areas of forest were killed by the rapid growth of peat, and the levels of the Alpine lakes rose suddenly, flooding many of the lake settlements. This climatic change did not last long; by the beginning of the Christian era, conditions did not differ greatly from current ones. Since then climatic variations have continued to occur, and although none has been as dramatic as that of 500 B.C., a perturbation known as the little ice age of the seventeenth century is a recent noteworthy example. The cause of these historical changes in climate remains shrouded in mystery. The rapid changes of climate in the past suggest to many that there exist instabilities affecting the balance of solar radiation.

Indeed, climate is primarily determined by the balance between the incoming short wave from the sun (principally light) and the loss of outgoing long-wave radiation (principally heat).

Three factors dominate the balance: the energy of the sun, the surface character of terrestrial regions (water, ice, vegetation, desert, etc.), and the transparency of the earth's atmosphere to different forms of radiated energy. In the last connection, the effect of clouds in making cool days and relatively warm nights is a matter of familiar experience. But clouds are a manifestation rather than an original determinant of weather and climate; of more fundamental significance is the effect of gases in the atmosphere, which absorb much of the radiation in transit from the sun to the earth or from the earth into space. Intense X-rays and ultraviolet from the sun, together with high-energy atomic particles, are arrested in the upper atmosphere. Only the narrow band of visible light and some short radio waves traverse the atmosphere without serious interruption.

There has been much controversy in recent years about conjectured over-all effects on the world's climate of emissions of carbon dioxide to the atmosphere from furnaces and engines burning fossil fuels, and some about possible influences of the exhaust from large rockets on the transparency of the upper atmosphere. Carbon dioxide placed in the atmosphere since the start of the industrial revolution has produced an increase in the average temperature of the lower atmosphere of a few tenths of a degree Fahrenheit. The water vapor that may be introduced into the stratosphere by the supersonic transport may also result in a similar temperature rise. In principle it would be feasible to introduce material into the upper atmosphere that would absorb either incoming light (thereby cooling the surface) or outgoing heat (thereby warming the surface). In practice, in the rarefied and windswept upper atmosphere, the material would disperse rather quickly, so that military use of such a technique would probably rely upon global rather than local effects. Moreover, molecular material will tend to decompose, and even elemental materials will eventually be lost by diffusion into space or precipitation to the surface. At intermediate levels, in the stratosphere, materials may tend to accumulate, though the mixing time for this part of the atmosphere is certainly less than ten years and may be a few months. If a nation's meteorologists calculated that a general warming or cooling of the earth was in their national interest, improving their climate while worsening others, the temptation to release materials from high-altitude rockets might exist. At present we know too little about the paradoxical effects of warming and cooling, however, to tell what the outcome might be.

More sudden, perhaps much briefer but nevertheless disastrous, effects are predictable if chemical or physical means were developed for attacking one of the natural constituents of the atmosphere—ozone. A low concentration of ozone ( $O_3$ , a rare molecular form of oxygen) in a layer between fifteen and fifty kilometers altitude has the utmost significance for life on land. It is responsible for absorbing the greater part of the ultraviolet from the sun. In mild doses, this radiation causes sunburn; if the full force of it were experienced at the surface, it would be fatal to all life—including farm crops and herds—that could not take shelter. The ozone is replenished daily, but a temporary "hole" in the ozone layer over a target area might be created by physical or chemical action. For example, ultraviolet at 250 millimicrons wave length decomposes ozone molecules, and ozone reacts readily with a wide range of materials.

At present, we can only tentatively speculate about modifying the short-wave radiation at its source, the sun. We have discovered major instabilities on the sun's surface that might be manipulated many years hence. In a solar flare, for example,  $10^{10}$  megatons of energy are stored in distorted magnetic fields. With advanced techniques of launching rockets and setting off large explosions, we may sometime in the future learn to trigger these instabilities. For the near future, however, modification will not be in the short-wave incoming radiation but in the long-wave outgoing radiation.

The usual schemes for modifying climate involve the manipulation of large ice fields. The persistence of these large ice fields is due to the cooling effects of the ice itself, both in reflecting (rather than absorbing) incoming shortwave radiation and in radiating heat at a higher rate than the usual ground cover. A commonly suggested means of climate modification involves thin layers of colored material spread on an icy surface, thus inhibiting both the reflection and radiation processes, melting the ice, and thereby altering the climate. Such a procedure presents obvious technical and logistic difficulties. For example, if one wished to create a surface coating of as little as one micron thickness to cover a square 1000 kilometers in size, the total material for this extremely thin coating would weigh a million tons or more, depending upon its density. So the proposals to dust from the air some of the globe's extended ice sheets are unrealistic and reflect a brute-force technique, taking no advantage of instabilities within the environment.

Although it may be technologically difficult to change an ice cap's surface character, and thus its thermal properties, it may be possible to move the ice, taking into account the gravitational instability of ice caps. The gravitational potential energy of water as a thick, high ice cap is much greater than it would be at sea level. This fact makes it possible, at least in principle, to devise schemes for bringing about a redistribution in the ice. Indeed, A. T. Wilson has proposed a cyclical theory for the Ice Ages, based on this instability.

The main points of Wilson's theory are as follows:

1. Antarctica is covered by an ice sheet several kilometers thick. Pressure at the bottom of the ice is great enough to keep the ice at or near its melting point; water is an unusual material in that a pressure increase lowers rather than raises its melting point. An increase in thickness of the ice sheet could result in melting at the bottom. The resulting ice-water mixture along the sole of the glacier would permit flow by a process of freezing and melting—a flow process much more effective than ordinary plastic flow.

2. If such an instability occurs, the ice sheet will flow out onto the surrounding sea, and a large shelf will be formed between Antarctica and the ocean around it. As a consequence, short-wave solar radiation will be reflected, and there will be enhanced loss of heat by radiation at the long wave lengths, causing cooling and the inducement of world-wide glaciation.

3. Once the ice shelf is in the ocean, it will begin to melt and eventually will be removed. The ice remaining on land will be much thinner than before. As the reflectivity of the southern hemisphere decreases with the melting of the Antarctic ice cap, the global climate will grow warmer again, corresponding to the start of an interglacial period. The ice cap will slowly form again.

Commenting on Wilson's theory, J. T. Hollin has noted the possibility of a catastrophic surge or advance of the ice sheet, such as has been recorded from small glaciers on numerous occasions. The largest surge yet reported is probably that of the ice cap in Spitsbergen, which advanced up to twenty-one kilometers on a front of thirty kilometers sometime between 1935 and 1938. There are also reports of glacial advances at speeds up to one hundred meters per day. Hollin speculates that, once the bottom-melting phase of a gravitationally unstable ice cap is reached, it will move quickly. In addition to trapped geothermal heat melting the ice at the bottom, there are additional contributions from frictional heat generated as the glacier scrapes along the solid ground.

If the speculative theory of Wilson is correct (and there are many attractive features to it), then a mechanism does exist for catastrophically altering the earth's climate. The release of thermal energy, perhaps through nuclear explosions along the base of an ice sheet, could initiate outward sliding of the ice sheet which would then be sustained by gravitational energy. One megaton of energy is sufficient to melt about 100 million tons of ice. One hundred megatons of energy would convert 0.1 cm. of ice into a thin layer of water covering the entire Antarctic cap. Lesser amounts of energy suitably placed could undoubtedly initiate the outward flow of the ice.

What would be the consequences of such an operation? The immediate effect of this vast quantity of ice surging into the water, if velocities of one hundred meters per day are appropriate, would be to create massive tsunamis (tidal waves) that would completely wreck coastal regions even in the Northern Hemisphere. There would then follow marked changes in climate brought about by the suddenly changed reflectivity of the earth. At a rate of one hundred meters per day, the center of the ice sheet would reach the land's edge in forty years.

Who would stand to benefit from such application? The logical candidate would be a landlocked equatorial country. An extended glacial period would insure near-Arctic conditions over much of the temperate zone, but temperate climate with abundant rainfall would be the rule in the present tropical regions.

#### FUTURE OF WEATHER AND CLIMATE MODIFICATION

The foregoing perhaps represents a more positive view of weather and climate modification than that held by many earth scientists. I believe this view is justified as it is based on three scientific and technological advances. First, understanding of basic meteorology has advanced to such an extent that mathematical models of the atmosphere here have been developed incorporating the most important elements. Physical processes in clouds, in turbulent exchanges at the surface, and in transmission of radiation through the atmosphere are no longer as mysterious as they once were. The volumes simulated by the models range from the size of a single cloud to the entire atmosphere: these models are no longer primitive representations.

Secondly, the advent of high-speed computers enables atmospheric models to be studied in greater detail. These computers have a peculiar importance to weather modification, since they will enable scientists to carry out extended experiments to test whether or not various schemes for manipulating the atmosphere are indeed possible and what the outcome should be.

The third advance lending support to expectations for weather and climate modification is the new array of instruments developed to observe and detect changes in the atmosphere. The most dramatic and perhaps the most powerful is the meteorological satellite, which provides a platform whence the atmosphere can be observed, not only in geographically inaccessible regions, but also with entirely new physical measurements. For example, meteorological satellites of the future will permit the determination of humidity, temperature, and pressure as averaged over substantial volumes of the atmosphere, providing quantities that are needed to develop the mathematical models. Sophisticated surface instrumentation, for observing detailed processes within smaller parts of the atmosphere, provides us with far more powerful tools with which to look at clouds and at the interaction of the atmosphere with its boundaries than those which were available ten or twenty years ago.

#### EARTHQUAKE MODIFICATION

What causes earthquakes? Over geological time, the irregular distribution of heat-producing radioactive elements in the rock layers gives rise to subsurface temperature differences between various parts of the earth. In the continents, granites and similar rocks have concentrated radioactive elements near the surface; no similar concentration has taken place in the suboceanic regions, which may as a result be more than one hundred degrees centigrade cooler than the corresponding subcontinental regions. Such variations in temperature along a horizontal line, due to the differences in the vertical distribution of heat-producing elements, give rise to large thermal stresses, causing strain analogous to that which cracks a glass tumbler filled with hot water. The strain tends to be greatest in regions of abrupt temperature change along a horizontal line through the earth's crust. The strain may be partially relieved by the slow convective flow of material in the deep earth which is thought by some geophysicists to push continents about. But the strain can also be relieved by sharp fractures or by movements along previous faults in rocks near the surface. Movement along a fault radiates energy outward, which results in an earthquake. Each year approximately 200 megatons of strain energy is released in this fashion, the largest earthquakes corresponding to energy of the order of 100 megatons. The energy released depends on the volume of material affected. The largest earthquakes take place along faults having a linear dimension of 1000 kilometers, whereas smaller ones take place along faults of one kilometer or less.

Major earthquakes tend to be located along two main belts. One belt, along which about eighty-five per cent of the total energy is released, passes around the Pacific and affects countries whose coastlines border this ocean, for example Japan and the west coast of North America. The second belt passes through the Mediterranean regions eastward through Asia and joins the first belt in Indonesia. Along these two belts, large earthquakes occur with varying frequencies. In California a large earthquake might be expected once every fifty to one hundred years, while Chile might expect such a disturbance once every ten to twenty years. Sometimes major earthquakes have occurred in regions ordinarily thought of as being free from risk. For example, the New Madrid earthquake of 1811-1812 devastated a large area of central North America but had only slight cultural effects because of the area's sparse population.

Today, our detailed understanding of the mechanism that causes an earthquake and of how the related instability can be triggered is limited. Only within the last few years have serious discussions of earthquake prediction begun, whereas moderately reliable weather forecasts have been available for about the last thirty to fifty years. Currently, substantial effort is being made, primarily by Japan and the United States, to develop techniques for forecasting earthquakes. These techniques are based to a large extent on the determination of changing strain conditions of materials in the rocks surrounding recognized fault zones. Of possible value is the observation that before an earthquake the accumulating strain accelerates.

Control of earthquakes is a prospect even more distant than that of forecasting, although two techniques have been suggested through recent experience.

1. In the course of the underground testing of nuclear weapons at the Nevada test site, it was observed that an explosion apparently released local strain in the

earth. The hypothesis is that the swift build-up of strain due to the sudden release of energy in an explosion discharges strain energy over a large volume of material.

2. Another method of releasing strain energy has appeared from pumping of underground water in the vicinity of Denver, Colorado, which has led to a series of small earthquakes. The hypothesis here is that underground water has provided local lubrication permitting adjacent blocks to slip by one another.

The use as a weapon system of the strain energy instability within the solid earth requires an effective triggering mechanism. A scheme for pumping water seems clumsy and easily detectable. On the other hand, if the strain pattern in the crust can be accurately determined, the phased or timed release of energy from smaller faults, designed to trigger a large fault at some distance, could be contemplated. This timed release could be activated through small explosions and thus it might be possible to use this release of energy stored in small faults at some distance from a major fault to trigger that major fault. For example, the San Andreas fault zone, passing near Los Angeles and San Francisco, is part of the great earthquake belt surrounding the Pacific. Good knowledge of the strain within this belt might permit the setting off of the San Andreas zone by timed explosions in the China Sea and Philippine Sea. In contrast with certain meteorological operations, it would seem rather unlikely that such an attack could be carried out covertly under the guise of natural earthquakes.

#### MODIFICATION OF OCEANS

We are still in the very early stages of developing the theory and techniques for predicting the state of the oceans. In the past two decades methods have been devised for the prediction of surface waves and surface wind distribution. A warning system for the tsunamis (tidal waves) produced by earthquakes has also been developed.

Certain currents within the oceans have been identified, but we do not yet know what the variable components are; that is, what the weather within the ocean is. Thus we have not been able to identify any instabilities within the oceanic circulation that might be easily manipulated. As in the case of the solid earth, we can only speculate tentatively about how oceanic processes might be controlled.

One instability offering potential as a future weapon system is that associated with tsunamis. These frequently originate from the slumping into the deep ocean of loosely consolidated sediments and rocks perched on the continental shelf. Movement of these sediments can trigger the release of vast quantities of gravitational energy, part of which is converted in the motion of the tsunami. For example if, along a 1000-kilometer edge of a continental shelf, a block 100 meters deep and ten kilometers wide were dropped a distance of 100 meters, about 100 megatons of energy would be released. This release would be catastrophic to any coastal nation. How could it be achieved? A series of phased explosions, perhaps setting off natural earthquakes, would be a most effective way. I could even speculate on planning a guided tidal wave, where guidance is achieved by correctly shaping the source which releases energy.

#### BRAIN WAVES AROUND THE WORLD?

At heights of forty to fifty kilometers above the earth's surface substantial numbers of charged particles are found which make this part of the atmosphere, the ionosphere, a good conductor of electricity. The rocks and oceans are also more conducting than the lower atmosphere. Thus, we live in an insulating atmosphere between two spherical conducting shells or, as the radio engineer would put it, in an earth-ionosphere cavity, or wave guide. Radio waves striking either conducting shell tend to be reflected back into the cavity, and this phenomenon is what makes conventional long-distance radio communication possible. Only recently, however, has there been any interest in natural electrical resonances within the earth-ionosphere wave guide. Like any such cavity, the earth-ionosphere wave guide will tend to sustain radio oscillation at certain frequencies in preference to others. These resonant frequencies are primarily determined by the size of the earth and the speed of light, but the properties of the ionosphere modify them to a certain extent. The lowest resonances begin at about eight cycles per second, far below the frequencies ordinarily used for radio communication. Because of their long wave length and small field strength, they are difficult to detect. Moreover, they die down quickly, within one sixteenth of a second or so; in engineering terms, the cavity has a short time constant.

The natural resonant oscillations are excited by lightning strokes, cloud-to-ground strokes being a much more efficient source than horizontal cloud-to-cloud discharges. On the average, about one hundred lightning strokes occur each second (primarily concentrated in the equatorial regions), so that about six lightning flashes are available to introduce energy before a particular oscillation dies down. A typical oscillation's field strength is of the order of 0.3 millivolts per meter.

The power of the oscillations varies geographically. For example, for a source located on the equator in Brazil the maximum intensity of the oscillation is near the source and at the opposite side of the earth (around Indonesia). The intensity is lower in intermediate regions and toward the poles.

One can imagine several ways in which to increase the intensity of such electrical oscillations. The number of lightning strokes per second could be enhanced by artificially increasing their original number. Substantial progress has been made in the understanding of the physics of lightning and of how it might be controlled. The natural oscillations are excited by randomly occurring strokes. The excitation of timed strokes would enhance the efficiency with which energy is injected into an oscillation. Furthermore, the time constant of the oscillation would be doubled by a fourfold increase in the electrical conductivity of the ionosphere, so that any scheme for enhancing that conductivity (for example, by injecting readily ionized vapor) lowers the energy losses and lengthens the time constant, which would permit a greater number of phased lightning strokes before the decay of an oscillation.

The enhanced low-frequency electrical oscillations in the earth-ionosphere cavity relate to possible weapons systems through a little-understood aspect of brain physiology. Electrical activity in the brain is concentrated at certain frequencies, some of it extremely slow, a little around five cycles per second, and very conspicuous activity (the so-called alpha rhythm) around ten cycles per second. Some experiments have been done in the use of a flickering light to pull the brain's alpha rhythm into unnatural synchrony with it; the visual stimulation leads to electrical stimulation. There has also been work on direct electrical driving of the brain. In experiments discussed by Norbert Wiener, a sheet of tin is suspended from the ceiling and connected to a generator working at ten cycles per second. With large field strengths of one or two volts per centimeter oscillating at the alpha-rhythm frequency, decidedly unpleasant sensations are noted by human subjects.

The Brain Research Institute of the University of California is investigating the effect of weak oscillating fields on human behavior. The field strengths in these experiments are of the order of a few hundredths of a volt per centimeter. Subjects show small but measurable degradation in performance when exposed to oscillating fields for periods of up to fifteen minutes.

The field strengths in these experiments are still much stronger, by a factor of about 1000, than the observed natural oscillations in the earth-ionosphere cavity. However, as previously noted, the intensity of the natural fluctuations could be increased substantially and in principle could be maintained for a long time, as tropical thunderstorms are always available for manipulation. The proper geographical location of the source of lightning, coupled with accurately timed, artificially excited strokes, could lead to a pattern of oscillations that produced relatively high power levels over certain regions of the earth and substantially lower levels over other regions. In this way, one could develop a system that would seriously impair brain performance in very large populations in selected regions over an extended period.

The scheme I have suggested is admittedly far-fetched, but I have used it to indicate the rather subtle connections between variations in man's environmental conditions and his behavior. Perturbation of the environment can produce changes in behavior patterns. Since our understanding of both behavioral and environmental manipulation is rudimentary, schemes of behavioral alteration on the surface seem unrealistic. No matter how deeply disturbing the thought of using the environment to manipulate behavior for national advantage is to some, the technology permitting such use will very probably develop within the next few decades.

#### SECRET WAR AND CHANGING RELATIONSHIPS

Deficiencies both in the basic understanding of the physical processes in the environment and in the technology of environmental change make it highly unlikely that environmental modification will be an attractive weapon system in any direct military confrontation in the near future. Man already possesses highly effective



tools for destruction. Eventually, however, means other than open warfare may be used to secure national advantage. As economic competition among many advanced nations heightens, it may be to a country's advantage to ensure a peaceful natural environment for itself and a disturbed environment for its competitors. Operations producing such conditions might be carried out covertly, since nature's great irregularity permits storms, floods, droughts, earthquakes, and tidal waves to be viewed as unusual but not unexpected. Such a "secret war" need never be declared or even known by the affected population. It could go on for years with only the security forces involved being aware of it. The years of drought and storm would be attributed to unkindly nature, and only after a nation was thoroughly drained would an armed takeover be attempted.

In addition to their covert nature, a feature common to several modification schemes is their ability to affect the earth as a whole. The environment knows no political boundaries; it is independent of the institutions based on geography, and the effects of modification can be projected from any one point to any other on the earth. Because environmental modification may be a dominant feature of future world decades, there is concern that this incipient technology is in total conflict with many of the traditional geographical and political units and concepts.

Political, legal, economic, and sociological consequences of deliberate environmental modification, even for peaceful purposes, will be of such complexity that perhaps all our present involvements in nuclear affairs will seem simple. Our understanding of basic environmental science and technology is primitive, but still more primitive are our notions of the proper political forms and procedures to deal with the consequences of modification. All experience shows that less significant technological changes than environmental control finally transform political and social relationships. Experience also shows that these transformations are not necessarily predictable, and that guesses we might make now, based on precedent, are likely to be quite wrong. It would seem, however, that these nonscientific, nontechnological problems are of such magnitude that they deserve consideration by serious students throughout the world if society is to live comfortably in a controlled environment.

**AUTHOR'S NOTE:** In the section on weather modification I have drawn heavily on Weather and Climate Modification (National Academy of Sciences, National Research Council, Washington, 1966). A.T. Wilson's paper on "Origin of Ice Ages" appeared in *Nature*, vol. 201, pp. 147-49 (1964), and J.T. Hollin's comments in vol. 203, pp. 12-16 (1965). Release of tectonic strain by underground nuclear explosion was reported by F. Press and C. Archambeau in *Journal of Geophysical Research*, vol. 67, pp. 337-43 (1962), and man-made earthquakes in Denver by D. Evans in *Geotimes*, vol. 10, pp. 11-17. I am grateful to J. Homer and W. Ross Adey, of the Brain Research Institute of the University of California at Los Angeles, for information on the experimental investigation of the influence of magnetic fields on human behavior.

**Senator PELL.** And there are no new potential weapons that could be added to that list, are there?

**Mr. MacDonald.** Many of the ideas expressed in that article have progressed in the sense that those technologies I discussed have been developed to a much greater extent today than they were in 1966.

**Senator PELL.** But there are no new technologies that did not appear in that, are there?

**Mr. MacDonald.** Not to my knowledge.

**Senator PELL.** Thank you.

#### COUNCIL ON ENVIRONMENTAL QUALITY

As a former member of the Council on Environmental Quality, were you part of Mr. Pollack's study committee they had about a year and a half ago on this subject?

**Mr. MacDonald.** No, the council on Environmental Quality was not included in the Under Secretary's committee looking at this problem.

Senator PELL. Did the Council on Environmental Quality ever have any problem obtaining the information concerning DOD operations in the field of weather modification?

Mr. MACDONALD. The Council on Environmental Quality as I think applies to other agencies, did not have that information made available to it.

#### OTHER POINTS IN MR. ST. AMAND'S STATEMENT

Senator PELL. Do you have any particular comments besides the question of the potential use of earthquakes with regard to Mr. St. Amand's statement? Were there any other points particularly that piqued you one way or the other?

Mr. MACDONALD. I would have to look at the statement in detail. I prefer not to comment at this time.

#### EXECUTIVE BRANCH'S REFUSAL TO ARTICULATE NATIONAL POLICY

Senator PELL. What in your personal view and opinion is the primary reason for the executive branch's refusal to articulate a national policy on this issue?

Mr. MACDONALD. I think the reason in part is a bureaucratic one in the sense that there are conflicting interests. In part it is—it's my feeling, I have no direct knowledge—that other than the references contained within the Pentagon Papers, we did use certain techniques in Southeast Asia and that making the public aware of the use of these techniques might be damaging in a variety of ways.

In part I think there is serious concern as to whether restricting or prohibiting by international agreement the development of these methods as weapons will discourage the development of environmental modification techniques for peaceful purposes. I don't think there is a simple answer. It is one that bothered me a great deal when I was in the Council and so bothers me today.

#### U.S. POSITION AT STOCKHOLM CONFERENCE

Senator PELL. You were a member and I was adviser to the U.S. delegation to the Stockholm Conference. Looking back on that, I remember I was surprised at the sensitivity of our delegation to the questions of environmental modification of warfare that were being posed at the time. I recall also being the only member of the delegation who objected to our knee jerk reaction to Palme's speech which said frankly what was in everybody's mind who was there.

What was your view in retrospect? What is the reason for the ultrasensitivity, you remember, when we insisted on somewhat gutting the recommendation saying "where feasible" in recommendation 218. I was curious about what you thought of our reaction to Palme, the oversensitivity.

Mr. MACDONALD. Basically, the delegation was, of course, under instructions. The instructions were formulated in this area principally by the National Security Council at that time. I think the situation exists today where there is no overall policy as to whether or not weather modification should be used or weather modification techniques be developed as weapons of war.

When we were in Stockholm I would say that there was no agreed-upon policy.

#### OPERATION ROME PLOW

Senator PELL. There is no secret about Operation Rome Plow where they knocked down the trees in Vietnam. It seems to me that falls in the environmental modification and yet our sensitivity to it being even discussed was an extreme.

My own theory about it was that Mr. Ehrlichman, who at the time I think had certain bully-boy characteristics, was at the Stockholm Conference in the early part and back and forth. I don't know if you care to hypothesize on an opinion.

Mr. MACDONALD. I think that it extended to direct instructions from the White House and the National Security Council and that was the reason. It was not just the members of the delegation, including Mr. Ehrlichman.

#### APPROPRIATE AGENCY TO CONDUCT NEW STUDY

Senator PELL. Do you believe that the Defense Department should be the agency to conduct the new study mentioned in Mr. Pollack's statement? I think we have moved quite far ahead in that a study is being ordered by the President.

As you know, in Government you have to go through a series of studies before any action is ever taken, and you never know whether it is going to be one study or several studies, but each study is at least one slow step forward.

Mr. MACDONALD. Yes; I was delighted to hear this morning from Mr. Pollack that such a study has been ordered. I will only recall that this is an issue that has been before this administration for a number of years. You have raised it with the administration. It came up in connection with the Secretary of State's confirmation hearings. It has been there.

And only now is a particular agency requested to carry out such a study. I think that the Department of Defense is completely inappropriate to carry out such an investigation. It has a vested interest in it. I think it would be more appropriate, for example, to ask the Arms Control and Disarmament Agency to take on such a study. And you might argue that it also has a vested interest.

You might ask an independent body from outside the Government to look into this question. To ask the Defense Department to look into it is not the way to proceed.

Senator PELL. It reminds me of what a present colleague and former member of the executive branch once said about having a coalition government—it is like putting the fox into the hen coop.

Mr. MACDONALD. Yes; the hen coop or whatever, but this is clearly a case in which you are asking the principal participants of a certain activity to judge whether that activity is good for the country as a whole and I just think that is bad.

Senator PELL. I would agree.

I thank you very much indeed for coming down from New Hampshire and we are glad you were with us today.

Mr. MACDONALD. Thank you very much.

Senator PELL. The next witness is Dr. Thomas Malone, director of the Holcomb Research Institute, Butler University, Indianapolis, Ind., and formerly of the University of Connecticut.

**STATEMENT OF DR. THOMAS F. MALONE, DIRECTOR, HOLCOMB RESEARCH INSTITUTE, BUTLER UNIVERSITY, INDIANAPOLIS, IND.**

Mr. MALONE. Thank you very much.

My name is Thomas F. Malone. I am speaking as a private citizen, but from a background of onetime Chairman of the National Academy of Sciences' Panel on Weather and Climate Modification and Vice President of the International Council of Scientific Unions and Secretary General of its Committees on Atmospheric Sciences, and currently a member of the President's National Advisory Committee on Oceans and Atmosphere where I have special responsibility for their position on weather modification.

Mr. Chairman, in view of the advanced hour, it might be helpful if I simply submitted my statement and presented my views on what I think you identified as the key issues in this hearing.

Senator PELL. That would be most agreeable and the statement will be inserted in the record as if read.

Mr. MALONE. Thank you, sir.

**WHY EXECUTIVE BRANCH POLICYMAKERS ARE SLOW TO RESPOND**

I think the issues are, first, why are the policymakers in our executive branch so slow to respond to this issue, which, as you know, I raised 8 years ago before hearings of the Senate Commerce Committee pointing out the "nightmare" versus the "vision" of the atmospheric scientists in this vexing field.

And I think there are two reasons. One is that I don't believe that the dimension of the issues involved in environmental problems have really been sensed by these people who have shown great courage and imagination in establishing detente with potential adversaries. It has been too narrowly viewed as a warfare weapon rather than the larger implications of an emerging capacity to exercise meaningful control over our environment.

I think it is a lack of awareness of what we are really talking about.

Second, I think that in view of the secrecy which veils the Southeast Asia operation, one is led to question whether or not the claims of effectiveness have not been extravagant. This has been true of weather modification in general and since one doesn't have access to these reviews—these assessments—one is not able to evaluate them.

But I have a small still voice within me which says that it is not unthinkable that the claims of military effectiveness have been exaggerated just as the claims of civilian effectiveness in this field have frequently been exaggerated by well-meaning honest people whose enthusiasm exceeds their perception.

So that would be my views on this key question that you have raised.

## ADEQUACY OF MEASURES PROPOSED

The second key question I believe is the adequacy of the measures which are proposed. I share Professor MacDonald's keen disappointment at the selection of DOD as the agency to carry out the study. I have fine, competent friends, colleagues, in DOD who I admire. This is just the wrong place. This kind of responsibility in the executive department belongs in the State Department.

Senator PELL. Or ACDA. Wouldn't that be the logical place?

Mr. MALONE. ACDA would be appropriate. I believe that the implications here—that is, of this matter escalated to its proper importance—transcends the responsibility of ACDA and becomes a matter of international science policy which I believe would fall within the purview of the State Department.

And I might say, sir, that another institution which might be helpful is the newly established Office of Technology Assessments [OTA] that is attached to the Congress.

There are two mechanisms.

In addition, there is a precedent for establishing special commissions to look into these matters, and I think that this would be a very appropriate way to examine some of these larger broader issues and to bring this down from the realm of hyperbole to the practical.

Let me just mention a few of the great societal issues which I think are related to the whole question of environmental modification.

One is the energy problem which is vexing us today. It is clear that with a doubling time of the order of a decade or two in the production of energy, we are really racing pell-mell toward that time when we may be forced to choose between more people or limitations on the energy per capita, because of the concentration of waste heat dumped into the atmosphere and the possibility that it would induce unacceptable perturbations and affect our climate.

A second area is the food issue where the potential doubling or quadrupling over the food requirements between now and the end of the century are going to strain our food producing capacities and they are going to make extremely important the utilization of the water and air resources and are going to result in desalination to provide irrigation, interruption of the hydrologic cycle with consequences of inadvertently modifying the climate that we should begin to address now.

The third area that I am concerned about is the natural catastrophe area. Last week I was in Miami listening to the head of the hurricane unit down there speaking of the frightful, frightening potential for casualties running into the tens of thousands in connection with storm surges moving on to the coastal zone where the population density has soared in the last decade or so.

Several options are available to ameliorate that hazard. One certainly is the diminution of the intensity of hurricanes. If that is to proceed, the whole operation will have to move to the Pacific Ocean, and in that case, we immediately get into an international operation.

So that what I am suggesting, sir, is that if we look at the whole matter of either conscious or inadvertent environmental modification and its relation to some of the great societal issues and the frightening policy decisions which are going to confront us within a matter of

decades, then our Government, our Nation, has a great opportunity to take a constructive attitude to frame the proper questions and to subsume within this context the military utilization of this capability.

And it is in that direction that I would hope that you could with your very effective persistence move the thinking of our policymakers in both the executive and legislative branches of the Government.

I would hope that these Commissions, the State Department, or OTA would pick out the societal issues which I have mentioned, assess the adequacy of our scientific knowledge to resolve the policy questions involved, identify the research needs, and propose the kind of global strategies which would help us all to address them.

#### SECURITY OF SEEDING IN SOUTHEAST ASIA

Finally, sir, I would say that there is the question of the rather sordid secrecy of the seeding in Southeast Asia. I have given my little apprehensions there that must remain as to whether or not national security has become intermingled with a veil which sort of covers up or shrouds extravagant claims. This could all be resolved very quickly if the relevant documents were declassified and put in the public domain and exposed to the kind of scrutiny which we, in the scientific community, have found very helpful in either reducing extravagant claims or conversely, as a matter of fact, identifying things not recognized within the scientific establishment.

Mr. Chairman, I think I might stop here in view of the hour and be responsive to your questions.

Senator PELL. Thank you very much.

#### ADMINISTRATION WILLING TO HAVE CLASSIFIED DISCUSSION

I think we moved a little bit ahead today. For the first time the administration has been willing, on a classified basis, to discuss this subject. Until now, even with the Senate Foreign Relations Committee in closed session, there was no openness whatsoever—no candor at all.

That is a long cry from declassification, and I agree with you that it should be done.

#### STUDIES ON WEATHER, GEOPHYSICAL MODIFICATION

Are you aware in the scientific community of any detailed studies on this general subject of weather and geophysical modification?

Mr. MALONE. Within the scientific community, of course, the National Academy of Science has addressed the weather modification. It has not addressed the broader geophysical modification issue—not that I am familiar with.

#### PUTTING ENVIRONMENTAL MODIFICATION INTO CONTEXT

Senator PELL. I agree with you, too, in your statement that these problems transcend national borders; they are really global, and I know I have become a member of and become very interested in the Club of Rome. The Club of Rome believes these problems concerning energy and food and the oceans and population transcend national borders. I would hope we might add into our thinking this idea of

scientific weather modifications, scientific actions of this sort, because increasingly actions that are taken within one nation's border will have an impact on another.

Mr. MALONE. I wish you could persuade the policymakers in the Government that world society is at a sort of crossroads. Our ability to manipulate information, to manipulate materials, to interfere with life processes, to hand them information, have all brought us to the stage where our per capita capacity to transform natural resources into goods and services is doubling every few decades.

This means there is a better life downstream.

On the other hand, we are increasing at about 5 percent per year our demand on natural resources and we are in danger of overstressing the carrying capacity of Planet Earth. It is, precisely for this reason that we need to explore these because which road we pick will not be decided by some large plebiscite but by what Johnny Von Neumann told us many years ago, by a long series of small correct decisions.

It is in that context I would hope our Government could put this whole matter of environmental modification.

#### COMMENDATION OF WITNESS

Senator PELL. I thank you and I thank you very much indeed, Dr. Malone, for coming to this hearing.

[Dr. Malone's prepared statement follows:]

#### PREPARED STATEMENT OF DR. THOMAS F. MALONE, DIRECTOR, HOLCOMB RESEARCH INSTITUTE, BUTLER UNIVERSITY, INDIANAPOLIS, IND.

Mr. Chairman: In preparing for these timely hearings, I read—and reread—the report of the Hearings on Senate Resolution 281 held in July of 1972 before your Committee. Three impressions remain with me following that review:

The remarkable unanimity of the scientific community in supporting the proposal that the United States Government exercise initiative and leadership in seeking international agreement to eschew the hostile use of environmental modification and, in particular, military weather modification—yet the seeming ineffectiveness of these views in making something happen.

The commendable initiative of your Committee in holding hearings that led to a recorded Senate vote in favor of the Resolution—and yet the lethargy of Congress in acting on a matter that was brought before them during the course of extensive hearings in 1966.

The sordid secrecy that shrouded the alleged weather modification operations in Southeast Asia—leaving the thoughtful reader wondering whether national security was *really* involved or whether the veil of classification was drawn over these activities to shield shoddy science and extravagant claims from the scrutiny of peer review by which the soundness, integrity, and effectiveness of scientific programs are maintained.

It is with the persuasiveness and the effectiveness of the arguments advanced by the scientists in favor of eschewing the hostile use of weather modification that I would like to dwell briefly this morning. My convictions are strong and they have remained unchanged since February 24, 1966, when I testified before the Committee on Commerce of the United States Senate and drew a sharp contrast between “the vision” of atmospheric scientists of a world in which “the benefits of weather and climate control are allocated equitably among nations by methods that will have been developed (through) \* \* \* a long sequence of small correct decisions” \* \* \* and “the nightmare” of atmospheric scientists of a world in which conflict \* \* \* has been aggravated by dispute over the rights to one of the most international of our natural resources—the atmosphere \* \* \* a world in which \* \* \* the problem of nuclear proliferation (is) replaced by the proliferation of an environmental modification capability.”

Many of the arguments that have been advanced by the scientists have been based on moral imperatives, that is, on the course of action that would follow from an ethical framework attuned to circumstances of the contemporary world. Others recognize the jeopardy in which large scientific programs of a necessarily international character might be placed by contaminating scientific efforts directed toward beneficial ends with other scientific efforts directed toward military ends. These arguments are fundamentally valid, but a new dimension is beginning to emerge that intensifies the urgency of the matter and provides a rationale of pragmatic self-interest that might turn out to be compelling when idealism fails to carry the day. This new dimension is concerned with societal issues that require courageous and imaginative public policy decisions if we are to avert a series of crises over the decade immediately ahead and is also concerned with the dependence on international agreement and cooperation to establish the knowledge base upon which these policy decisions rest.

Mr. Chairman, I would like to touch on three of these issues in the hope that you and your committee can cast them in a form that will be persuasive to both Houses of Congress.

The first has to do with the world "food crisis" which is so clearly impending, and so inextricably related to weather and climate that its intensity may be exacerbated or ameliorated by the manner in which we "manage" our atmospheric resources. It is a simple statement of fact that *agricultural technology* seeks to maximize productivity while *nature* seeks to maximize ecological stability—two goals which are incompatible. To satisfy the soaring world food demands, we have pushed productivity to such high levels that we have fostered a high degree of instability in our agricultural ecosystems. This instability interacts with natural fluctuations in weather and climate and could be grievously aggravated by inadvertent climate modifications associated with human activities. The thousands of deaths through starvation in the Sahelian region of Africa are a shocking testimony to this dangerous state of affairs. With world food demands increasing two to four fold by the end of this century, it is clear that our global agricultural system will be strained to the limit. We have seen during 1973, that world food problems interact intimately with our own national system of food production. I want to make two points:

World food production is sharply dependent on weather and climate and its fluctuations.

We must learn to anticipate climatic changes, whether occurring naturally or as a result of human and industrial activities. This problem can *not* be solved by a single nation. It must be and is being addressed by international efforts. Next summer there will be convened in Stockholm a special summer study addressed to the kind of programs that need to be mounted during the First GARP Global Experiment in 1977-78 in order to illuminate the physical bases of natural and man-made climatic changes. The success of these deliberations and the programs emanating from them would be markedly enhanced were they to be carried out within a milieu in which international agreements had been reached eschewing the hostile uses of weather modifications. There is much more than the success of a scientific program involved. What is involved is an effort to provide the body of knowledge upon which policy decisions vital to our national self-interest depend.

The second issue has to do with a "sleeper" in the energy crisis. It is crystal clear that our current energy shortages simply reflect imperfections and artificial barriers in the extraction, transportation, refining and distribution of fossil fuels. These are socio-economic-political problems which can be resolved. If one looks beyond the current set of difficulties, it is equally clear that we are going to have adequate energy for the next hundred years. In fact, with a doubling time of something like 15 years in the world consumption of energy, long before our fossil fuels are exhausted we may well be confronted with one of the most major policy decisions the world has yet confronted. I refer to the limited capacity of the biosphere to absorb heat without inducing unacceptable perturbations in global wind patterns and hence world climate. This matter is now under active study by the presidentially appointed National Advisory Committee on Oceans and Atmosphere which communicates directly with both the executive and legislative branches of our government. Simply put, the concentration of heat discharged into the atmosphere may turn out to reach a high enough value within the next hundred years that we will have to place constraints on the population, on the population distribution, or on the energy consumption per person. The policy



implications for the world, and in particular for our nation which has such a high consumption of energy per capita, are obvious. To assess the seriousness of this matter in a sound and thoughtful manner, to fashion the tools and techniques to analyze the relevant issues and to go about the task of acquiring the necessary knowledge to undergrid the policy decisions is an effort which no single nation could possibly undertake. Once again I am trying to make the point that the treatment of atmospheric problems *must* be internationalized in our own national self-interest.

The third issue concerns the matter of catastrophic hurricanes. If one simultaneously looks at the accelerating concentration of population along coastal zones and the seventy-year record of hurricane entries into these coastal zones, one is led to the sobering conclusion that we seem to be looked in on a course which will lead us inevitably to a catastrophic event in which many *tens of thousands* of lives will be lost in a single weather episode. In fact, one can make a categorical prediction that such an event will occur sooner or later unless land-use policies are drastically altered, construction codes are brought into consonance with the kind of storm surges that mathematical modelling of wind, waves and coastal topography indicate, or alternatively, we develop the capacity to influence the intensity of hurricanes or change their direction. Other options for dealing with this hazard may be identified as the problem achieves public visibility. In the meantime, prudence suggests that we move ahead with research of the kind carried on in the program called "Storm Fury" in order to shed some light on the possibilities of modifying hurricanes. Here again, however, we are faced with a compelling need for internationalization of the effort. A strong case can be made for moving the research activities from the Atlantic into the Pacific Ocean because of the higher frequency of hurricane type storms in that region of the world. But tinkering with hurricanes, however soundly the scientific experiment is designed, is an extremely sensitive matter. Hurricanes are notoriously capricious and there is a natural tendency to ascribe any erratic behavior to human intervention during the course of scientific investigations into the possibility of modifying either intensity or direction. Once again I hope I made clear that more than the scientific integrity or the successful conduct of an intrinsically interesting scientific experiment is at stake. If there were any thought that a capability to tamper with hurricanes might be used as an hostile measure against another nation, the development of the knowledge base of the research would be seriously crippled. I hope we will not wait until catastrophe *does* strike and tens of thousands of our fellow citizens are drowned, to take the action that seems to be so clearly indicated.

Mr. Chairman, in these brief remarks I have tried to differentiate between the point of view that international agreement on environmental modification should be sought because it is "good" and the point of view that at least several grave societal issues that directly affect the self interest of the United States require for their resolution the formalization of international understanding and agreement. Somehow it seems inconceivable to me that the policy makers in this great nation of ours who have shown such wisdom and imagination in opening up lines of communication with potential adversaries can not be persuaded that the course you propose is not only statesmanlike but pragmatically in our self interest. After eight years of frustration over the failure of our nation to exercise initiative in this matter, my hopes have been rekindled by these hearings.

Two items by way of conclusion:

Since the hearings in 1972 the Committee on Atmospheric Sciences of the National Academy of Sciences has published another report on *Problems and Progress in Weather and Climate Modification* and re-emphasized and reiterated a position taken earlier that: "In order to safeguard the life-sustaining properties of the atmosphere for the common benefit of mankind, the U.S. Government is urged to present for adoption by the United Nations General Assembly a resolution dedicating all weather-modification efforts to peaceful purposes and establishing, preferably within the framework of international nongovernmental scientific organizations, an advisory mechanism for consideration of weather-modification problems of potential international concern before they reach critical levels.

Finally, it is time that we put this murky matter of the military use of weather modifications in Southeast Asia behind us. Now that we have disengaged from active combat there is no reason, in my mind, that the documentation describing those operations and the evaluation of their effectiveness can now be declassified and made available to the scientific community. I am persuaded that this would have a salutary effect on the troublesome issues that revolve around this questionable course of action.

Senator PELL. Our final witness today is Prof. Howard Taubenfeld, of the Institute of Aerospace Law, Southern Methodist University of Dallas, Tex.

I notice you have a fairly lengthy statement, and I wonder if we could have this inserted in the record.

**STATEMENT OF DR. HOWARD J. TAUBENFELD, INSTITUTE OF AEROSPACE LAW, SOUTHERN METHODIST UNIVERSITY, DALLAS, TEX.**

Mr. TAUBENFELD. Well, sir, I am of Germanic descent, and it usually takes me about 2 hours to get to the verb. I do apologize to you for not having been able to furnish the statement before today. My wife, who is a political economist, and I work in these areas together, and sometimes the negotiations on an agreed draft are something like what I think must go on between the Senate and DOD.

In any event, I, in view of the hour and of your patience in sitting this long with all of us, would like to call attention just to a very few points and hope that you may have the chance to look at the document at some other time.

Senator PELL. And it will be inserted in full in the record.

**THE 1967 STUDY ON INTERNATIONAL IMPLICATIONS OF WEATHER MODIFICATION**

Mr. TAUBENFELD. Thank you. To begin with, our work is concerned only with the weather modification aspects of the proposed treaty. We have been working in the field of international implications of weather modification since 1967 when the State Department asked us to do a study for them on international implications.

That study was published in the External Research series of 1968, and I think has met the fate of many such studies. Just a few years ago I was happy to present to Prof. Dean Rusk a copy of the paper which he had asked for several years ago as Secretary of State and which obviously had never before wended its way up that far.

**AGREEMENT WITH LIMITING LARGE-SCALE HOSTILE MODIFICATION USE**

It is quite clear that we all agree with the idea of limiting large-scale hostile modification use. We agree with "dedicating all environmental work to peaceful purposes," just as we are all, most of us, still in favor of motherhood and apple pie.

The remarks that are contained in the paper, to some degree have been expressed by others here, and I would like to, in a sense, reverse what we did in the paper. We did try to comment on this draft treaty, but then to go on to some other matters that we are very concerned with, which are a takeoff from it.

**LANGUAGE OF TREATY**

I would like to suggest, as other have here, that the treaty as presented and as you yourself have suggested, sir, is in some ways too broad as far as language goes. I, myself, as an international lawyer looking at the world today, would not be particularly favorable to eliminating in this way what I would like to call small-scale use without getting into the question what "small scale" means. Weather modifica-

tion in its "local" aspects may be at least as humane as weapons that are currently permitted.

I would like, myself, to see a much broader approach to the use of weapons, and of course, in the use of war itself.

I would also, having been in the field for almost a decade, have to give a nod of appreciation to the work that has been done by groups like Naval Research people because they have advanced the general art of weather modification in a field where funding has experienced a decline. There might be some real problems in taking them out of the field if this is what it amounted to.

Moreover, and a point which perhaps could only be cautiously made by people in defense, but which I think really does need consideration, if it does become possible somewhere, sometime, by somebody to make or to initiate major climatic shifts, it would be my hope they would be reversible, and one needs knowledge in order to know what one would do if faced by this nearly total weapon.

I think some research which in a sense has this kind of military orientation, though it would be the same research as for other purposes, should be continued. However, as you said, it is not so much wording and particular small points of the treaty that are important.

Our main problem with the treaty is that in a way indirectly expressed by some of my predecessors here, the treaty is too narrow for what I see as the major problems which the world may very well confront in the not too distant future.

We have been talking about the shifting of climate as a major weapon and as a horror story. It might certainly, if it were possible and could not be countered by other weather weapons, be countered by the threat of use of nuclear retaliation.

You are talking about national survival. But when Dr. Teller a decade ago talked about weather as a possible source of the last World War, or the cause of it, I don't think he was talking about weaponry; he was talking about how important weather is to countries and the real threat that it would pose to any country to see substantial shifts, whatever their reasons, in its weather, and hence its resource base.

It is perfectly clear that climate shifting, or climate modification, if it developed in anybody's hands, would be bound to be destabilizing to the international system and would very probably be in one context or another a cause of war.

Our problem though is that any wide scale effects may very well be just as devastating to many countries, to many persons, to the earth itself. They come about from a use of climate modification in war or from experiments on a broad scale by some scientists. "Let us see if the Arctic ice really will go out if we try one of these things."

There has also been talk of at least two kinds of modification done entirely for local purposes. The Russians talk about reversing rivers in Siberia to provide more water in central Russia, which is definitely needed. It would also presumably mildly affect, if it did no more than that, their northern coast by warming it, and that would be useful to them.

There is talk about removing the Brazilian forest. Each of these might in turn cause a catastrophe on earth. Neither one is being done or is being contemplated as a weapon or even in any sense to seriously dislocate any other country, yet the effects are of concern to all of us.

## INTERNATIONAL PUSH BY UNITED STATES NEEDED

Our suggestion is that what is needed is an international push by the United States. I don't think anyone else will do it—an international approach to large-scale modifications. In this sense, the treaty suggestion may be unfortunate in focusing on weather modification as a weapon, although it is certainly a dandy way to get attention to the need of the field.

It isn't, I think, large-scale use of weapons that is the major concern, because it seems to be doubtful they would be used. They can be countered in other ways. Weather modification in turn; nuclear bombs, if necessary.

It seems to me we need to focus attention already on things which are going on, that is, the potential large-scale shifts caused by large-scale scientific experiments; large-scale changes for other purposes, and perhaps most particularly, large-scale industrialization.

It is perfectly clear, as the Stockholm Conference showed that you can't simply say to a developing country: "Don't industrialize." Development is a very complex question which has had attention focused on it and which I don't think you want to pay attention to here.

## RIGHTS OF EACH COUNTRY

We suggest in our 1968 study, and I didn't see any particular reason for shifting, that an overall approach even now to the problems of large-scale climatic shift (which would, of course, include large-scale shifts used as weapons) would have to start with the notion of the inviolability of any nation's resource base, including its right to its "normal" weather, whatever that was, so that all countries would be protected.

There is then the additional right of each country to permit or conduct controlled experiments to control and improve the national weather, so long as this is not undertaken aggressively, and is undertaken with due care for requisite over-all safety and for peaceful purposes, and does not affect other nations' parallel rights.

## NEED FOR MASSIVE INTERNATIONAL COOPERATION

You would need for all of this massive international cooperation through information sharing, consultation, joint programs, joint controls, perhaps licensing, to achieve beneficial use. You would need to provide against economic disaster and this might very well slow the developments. It is true you would also need international political consensus in a region, or worldwide, before any major modification efforts could be permitted and this too would slow the development.

## TREATY SOLVES ONLY PART OF CLIMATIC-CHANGES PROBLEM

My small fear, sir, is that even if there were a treaty in this form, if a treaty limited to the banning of large-scale use of modification techniques in war were accepted (and I think if it were limited to those large-scale uses it might be acceptable to our DOD) it is my fear that we might then believe that we would then have solved the problem of large-scale climatic changes. I think that we would have approached only a very small part of it.

We have much more argument in the paper but I think that is sufficient for this moment.

Senator PELL. Thank you very much.

#### HURRICANE MODIFICATION

Hurricanes may be a point I should have struck on before among the various weapons that have been mentioned. I noticed that you are professor of aerospace at Southern Methodist University.

Not now, but as the years go by, would we be able to create and direct and point a hurricane?

Mr. TAUBENFELD. I always answer questions like that by speaking as a professor of law. My advice on technological matters would be as follows:

It seems to me that there is scanty but good evidence that some effects on hurricanes is, are, whatever the word is, possible. The work will shift to the Pacific, as you know, in 1976 without participation of the Department of Defense for a number of reasons, and I would assume that it might be possible in time to steer major storms.

I don't know whether there is a notion within the state of the art foreseeably how one would create a stupendous storm of the type that a hurricane represents and steering is a word that the people in the field don't want to use.

In fact, one of the dilemmas now, I suppose is that it would be easier if there was feeling you could steer a hurricane. Right now what you can do, perhaps, is to spread it out a little bit and that leads to a question I now ask our scientist friends each time we meet as a study group on implication of weather modification. Which would you prefer, a hurricane that was coming in and would probably hit a shoreline 50 miles long at 100 knots, or one that was coming in at 85 and would hit the coast for 75 miles?

That is a terrible dilemma and I almost hope that science doesn't find the answers to hurricane modification.

I have no technical information as to whether this would be feasible. I would like to make one point on scientific information.

#### EFFECTS OF MAJOR INTERNATIONAL PROGRAMS

Dr. MacDonald, in his eloquent statement, spoke about halting this kind of research; that is, the potential of using weather modification or other environmental techniques for war.

We make a comment, maybe a suggestion if you choose to take it that way, that one might very well argue that GARP [Global Atmospheric Research Program] and all of the other major scientific programs in atmosphere should be halted because those are the kinds of programs that are going to demonstrate and give us the knowledge and perhaps give the basis for eventually doing this sort of thing, controlling the weather.

I don't think that most of the scientists have any feeling that these major international programs should cease and yet those are the ones I rather think, not the limited work in national defense laboratories, which are going to form the basis for ultimate weather modification on a very large scale conceivably.

Senator PELL. Thank you.

## INTERNATIONAL LAW AND WEATHER MODIFICATION

What international discussions have been taking place concerning the possible extension over weather modification of the body of international law that is being developed in connection with nuclear testing and chemical and biological warfare?

Have there been any international discussions on this subject we are talking about?

Mr. TAUBENFELD. Not formal that I know of; very little on the informal side. There are, as far as I know, and again speaking as a professor of law, there are certainly no formal international agreements that the United States and other countries participate in with respect to weather modifications.

The United States has talked informally to Canada when we wanted to seed over the Great Lakes. We have talked informally to Cuba and to the British about the Bahamas, about the hurricane work. We certainly talked to the Philippines about potential hurricane modification. The Japanese we are talking to informally because they are very upset about the possibility of our doing hurricane work and typhoon work in the Pacific and I don't know if anyone has talked to the Chinese Communist Government about modification. I would be interested in their reaction.

Senator PELL. If it was correct that the United States employed weather modification techniques in the Vietnam war, specifically the insertion of silver iodine in cloud formation, does such an operation violate any present existing principle of international law?

Mr. TAUBENFELD. As far as I am concerned and as far as my studies have gone (I have had two teams of students trying to work this up, too), the answer in my judgment is no.

## JUSTIFYING WEATHER MODIFICATION UNDER INTERNATIONAL PRINCIPLES OF SELF-DEFENSE

Senator PELL. Do you believe the United States can justify the use of weather modification as a weapon under the international principles of self-defense?

Mr. TAUBENFELD. If you are talking about rights that involve also consideration of United Nations Charter, that is, no use of armed force except in self-defense, then we can only justify any use of force in that context. I would have to, at this stage of international relations, and considering what I judge to be the very limited capabilities of weather modification techniques, answer a little bit as Pierre St. Amand did in the quotation you read.

Weather is, if you like, a potential weapon, and I see no reason why it should not be used, legally speaking. I cannot in fact myself see any reason why it should not, in the present state of the arms control legal framework, be used from the moral point of view. If it is possible to prevent the enemy from getting to the battlefield with guns and equipment by making a road muddy, it is very hard for me to see why that should be illegal when it is permissible to blow him up once he gets there. I find that a dichotomy that is very hard to understand.

Now, if you are talking about some future worth, in which we have much sounder controls over all kinds of weapons in fighting, I would like to reconsider that.

## COMMENDATION OF WITNESS

Senator PELL. Well, I thank you very much indeed, Professor Taubenfeld, and thank your wife for her contribution to your statement which we look forward to enjoying. And this concludes this hearing of the subcommittee which will now adjourn subject to the call of the Chair.

[Dr. Taubenfeld's prepared statement follows:

PREPARED STATEMENT OF DR. HOWARD J. TAUBENFELD, INSTITUTE OF AEROSPACE LAW, SOUTHERN METHODIST UNIVERSITY, DALLAS, TEX.

While the evidence that the United States was probably engaging in some form of weather modification activities in Southeast Asia seems to be one of the most important generators of current efforts to bar, by treaty, environmental intervention by the military,<sup>1</sup> some commentators have been concerned with the possibly disastrous effects of conscious and unintended large-scale weather modification activities for many years now.<sup>2</sup> For a number of reasons, developed hereafter, while we remain very much disturbed by the major political conflicts and serious systemic destabilizations which can be expected if certain large-scale weather modification techniques become operational we can only support the creation of a treaty of the type contained in "the Pell resolution" after modifications and then with some remaining reservations.

We do not propose to rehearse in detail here matters which earlier subcommittee hearings and several other publications have examined extensively. In brief, these earlier materials, as well as many discussions over the years among concerned individuals<sup>3</sup> suggest that support for the Pell Resolution comes from diverse sources and concerns, most of which contain the kernel of an important consideration for society. In varying degrees, these include concern over (a) the potential risk of major and/or permanent damage to the world environment or to that of a country from unrestrained intentional large-scale wartime modification activities; (b) the possibility that modification as a weapon may be indiscriminate in its effects, and/or its results may be very difficult to control or even to predict; it would thus tend to damage the civilian, as well as the military component of an enemy, and, indeed, it might damage non-enemy regions as well, perhaps significantly, for it might trigger much larger climatic changes than were intended. In general, these two can be summed as the fear of a deliberately induced poorly-controlled natural catastrophe; (c) it might be most useful primarily against "civilian" targets; (d) the possibly destabilizing effects of weather-switching knowledge in the hands of one or more nations which could use it as a threat of huge scale damages in wartime and therefore as a type of "total weapon," or simply as a means of improving their own weather, in a way which might damage the weather of others significantly; (e) the feeling among scientists and others that "science" and the work of well-meaning "scientists" should not be used for such purposes as weaponry and certainly not for the elaboration of new "total weapons" of this type; (f) the feeling that (1) any move or (2) any credible, safe move towards "arms control" is useful—a "step in the right direction" towards establishing, eventually, an overall system of arms limitation, and control, and binding international conflict resolutions institutions; (g) the feeling that one is here intervening in God's handiwork and that this is, of necessity, wrong and dangerous. Of these, it is primarily the first three and most especially concern over the possible emergence of what might well be a new total weapon even less controllable than the existent ones which are alluded to in the Resolution and the draft treaty as bases for concerned action. We will return briefly to all but the last of these other concerns as well.

To accomplish its ends, the treaty proposes a ban, "at any place," on "any environmental or geophysical modification activity as a weapon of war" and on "any research or experimentation" directed to that end, while formally excluding "any research, experimentation, or use for peaceful purposes." Weather modifica-

<sup>1</sup> See, generally Davis, "Weather Warfare: Law and Policy," 14 *Ariz. L. Rev.* 659-688 (1973), and sources cited.

<sup>2</sup> See Taubenfeld & Taubenfeld, *External Research Series*, U.S. Dept. of State, 1968: "The International Implications of Weather Modification Activities," "Some International Implications of Weather Modification Activities," XXIII *Int'l. Org.* 808 (1969), and sources cited in these two items.

<sup>3</sup> For example, at the all day meeting on weather modification at the AAAS meeting here in Washington in December, 1972.





adopting a conflict resolution strategy relying primarily on such a self-negating agreement as that no state will harm another by inducing environmental or weather changes without its consent. Such a self-denying system has not worked in the past and cannot be expected to work in the long run to control international conflict over resources and the weather as a major resource. The problems are obvious. What about those states initially poorly endowed with good weather like the Soviet Union? Once they learn how to improve their situation and become strong enough to challenge the status quo, they can be expected to make efforts to recarve the status quo distribution of good weather even if that should happen to impose some losses on other states. They may try to get consent by threat or threaten war for retaliation. Hard bargaining and repetitive international crises and escapades of brinksmanship can be expected if improving one nation's weather dramatically must entail serious losses to another—unless these potentialities are somehow successfully neutralized by better conflict resolution machinery than has been adumbrated at the international level in the past.

This can be thought of as another version of the ancient problem of maintaining the peace: how to accomplish and accommodate peaceful changes of a redistributionary nature in a system in which the consent of the damaged parties has to be obtained, not primarily for legal reasons but because otherwise they may be expected to fight for the status quo if they believe that will help them improve the outcome. Various ways of imposing changes in favor of the strong at least, which are short of war, do exist, for example, by diplomacy, including promises, threats and various expressions of superior bargaining power based on various sources of power, economic, geographic, psychological-legal, as well as political, etc. all compounded together in some international forum like the U.N. (A court won't do for the Power demanding more than its status quo rights.) But all too often war has become the ultimate engine of redistributionary change in the international system. In conclusion then, though we do suggest that any treaty on weather and environmental modification adopt this normal legal and political strategy for allowing a sovereign the freedom to act to improve his knowledge or welfare, to modify the weather, for example, only with the consent of other damaged parties in cases where these activities are likely to affect other nations' weather and resource bases in ways they do not consider desirable, we do not consider this would be likely to be in the long run a sufficient design of a political-institutional setting for accommodating major international weather modification possibilities peacefully into the international system, particularly if redistributions are unavoidable—if some weather must be worsened, as seems likely. As a beginning, as a part of a strategy for which there is good historic precedent—for keeping the peace until a more adequate institutional design can be negotiated, we propose such an approach, with the caveat that it does have a conservative status quo bias and therefore is likely to be challenged eventually on this ground by nations which might gain disproportionately.<sup>7</sup>

At least initially it is likely to constrain somewhat the pursuit of scientifically or politically dangerous experimentation to require that all likely significantly affected parties be (1) identified and (2) consulted for their agreement. Note at present levels of scientific knowledge even the first of these, the identification of all parties likely to be impacted in the long run by a modification experiment or program requires much more information than is presently available.<sup>8</sup> To get this would necessitate normally much more "experimentation in computers" or if it is absolutely necessary to use a human environment as a laboratory, this would in logic require both careful precautions to limit the effects on humans and their environment of experiments to find out about impacts—and far more comprehensive efforts to compensate those damaged in this pursuit of essential scientific knowledge than has been traditional even in the traditional U.S. approach to the liability of those who affect others deleteriously in the pursuit of knowledge for the benefit of all by scientific experimentation. Thus, in sum, we suggest that, to protect humanity, its weather and ecosystem and the resource bases of the nations of the world community from deliberate or unexpected but in principle foreseeable damage due to scientific experimentation or, later, implementation in weather modification, seismic manipulations, etc. that a treaty be sought on the broader lines suggested above rather than on the narrower Pell approach.

<sup>7</sup> And by some scientists who are likely to dislike any long run constraints, no matter how politically or even biologically sound, on their freedom to explore.

<sup>8</sup> For example alternative methods of intentionally or unintentionally melting the Arctic ice cap is one major experiment in nature, frequently mentioned in the literature which quite possibly might effect changes in major weather patterns globally in ways that are debated. Scientists seem agreed already that anything like this, with potentially world-wide consequences should not be undertaken until better understood, or should be undertaken only after careful worldwide scientific scrutiny. We have suggested that worldwide political scrutiny should likewise be required despite the implied delays in experimentation.

If major conflicts over the environment or over the distribution of good weather are allowed to develop because some states are likely to be damaged, whether or not deleterious effects are intended by those states seeking to modify the status quo of nature to their own advantage, major world power confrontations in which the use of "total weapons" of one kind or another are considered, seem likely. In such a case (1) it seems on the face of it very likely that it would be difficult to enforce a Pell-style treaty of self-denial of "the weather weapon" and (2) at first blush, at least, it would appear in these circumstances, not necessarily desirable to do so. Major weather-switching might under some circumstances be the most preferable "total weapon," allowing, for instance, human life to persist and, in the good climes after the peace (presumably occupied by the winners) even to prosper. Unless, of course, as also appears likely in the case of nuclear powers, the would-be losers would respond with other even less humane total weapons, i.e. with nuclear devices—or at least pose a credible threat to do so.

It seems worth briefly exploring these lines of reasoning, even despite the widespread distastefulness of such analyses. Judging from past experiences with disarmament commitments the credibility of a self-denying treaty obligation to eschew using major weather modification as a weapon is likely to be poor in times of major war. Should these technologies be achieved, as suggested, it can be expected they will be used whenever, after all the circumstances are considered, it appears likely to be profitable for a state to use them. In this case, the most probable techniques involved seem unlikely to be secret or to require significant conversion to be switched from peaceful to wartime purposes. Since they are also likely to be generally very broadly sought after and available as a relatively cheap, potential source of economic self-help, most nations, large and small, are likely to have credible access to this class of potentially devastating weapons. Also, this could be expected to be an "n-country" world in the case of the "weather weapon" very soon after scientific discovery. How then could any nation really rely on a Pell-type self-denying treaty to protect it from this potentially total weapon?<sup>9</sup> Indeed, especially for small non-nuclear states this would appear to be the optimal total weapon readily available, cheap and less likely to lead to accidental total irreversible damage or annihilation. In sum, it seems quite reasonable to guess that, since the technology of weather switching is likely to be widely available and to result in a less devastating "total" weapon than nuclear devices, that threat to resort to it, if such threats were not made illegal, might become relatively frequent in the present international system. This might, indeed, also increase the risk of a nuclear counter threat or even a nuclear riposte by the nuclear powers.

Thus it seems worth attempting to put at least a legal ban on aggressive use of major weather switching or environmental modification. Also ultimately it seems likely that it would be this—this likelihood that if major deleterious weather modification became possible, it would become part of the menu of terrors which the nuclear power of the nuclear powers, the most total weapon, is balancing, which can be expected to be the real enforcement behind a Pell type self-denying proclamation prohibiting the resort to weather and environmental modifications.<sup>10</sup> But again this promises to work most securely against non nuclear powers. How to effectively deter Soviet or Chinese aggressive self-improvement of their initial weather endowment remains unclear and crucially important. Again a general ban on the weather weapon, plus a ban on damaging others without consent by environmental modifications would at least establish a tenable legal posture for the rest of the world, which would, no doubt, have to be supplemented by some creative machinery for international weather-environment redistributionary conflict resolution.

In sum, it appears crucial to design a system for managing all important international conflicts over weather and the environment, which are implicit in an unrestrained scientific free-for-all to discover these techniques of manipulation of nature, followed by an unconstrained economic competition to grab off the best modification of the original natural distribution. It is these competitions among major powers which are likely to be radically destabilizing in this international system; and which therefore attention should focus upon primarily.

<sup>9</sup> Indeed, the weather weapon may never be used, as gas has not generally been since the First World War, because it is too difficult or costly to control and might boomerang.

<sup>10</sup> Should the international system some day succeed in removing this nuclear deterrent to aggressive weather switching for peaceful or war purposes then the self-denying obligation not to use weather-environment aggressively or to damage other nations even for peaceful purposes could again lack enforceability and credibility. Even so, since most nations could quite likely be expected to be able to resort to the weather weapon, it is less likely that this would lead to a unilaterally destabilizing disarmament. And more important, a world that could achieve a credible nuclear disarmament would presumably provide as well a much safer, less volatile world system than the primitive community we have been assuming which relies heavily for stability on this balance of terrors.

In addition, it seems evident that it has to be the world's business since it is likely to be a cause of major international conflict if a new ice age—or some other major environmental perturbation is precipitated by nation A's use of wide-scale modification in a war with nation B, or by the industrialization of Africa,<sup>11</sup> or the clearing of the Brazilian forests, or by the scientists of country C in experimenting with climatic shifts, or by the actions of the Russian state in seeking to change the direction of rivers to bring irrigation water to central Russia or to warm an Arctic port. We do not suggest that all issues be lumped together or that they can be treated identically, but some potentially productive approach to all of them is now called for.

Furthermore, since we can assume that no nation would like any other nation to be able to, or to have a legal right to, initiate major weather changes which would affect it deleteriously, and since at present no nation has achieved that capacity, this would seem a reasonably promising time to seek a generally beneficial treaty arrangement for the control of damaging intervention in the weather, climate or environment. Perhaps a treaty (or even a UN declaration), of the type we suggested in 1968, is in order on the Peaceful Uses of Weather Modification Capabilities. In contrast with the present Pell proposal we feel this should include an attempt to foresee and neutralize as far as possible all the important dangers to the peace potentially implicit in these new technologies. Such an effort would include pledges on

(1) The inviolability of all nations' resource bases, including the rights to their normal moisture and their weather.<sup>12</sup>

(2) The right of each nation to permit or conduct controlled experiments to control and improve the national weather so long as this is not undertaken aggressively but undertaken with due care for the requisites of safety and for peaceful purposes and does not affect other nations' parallel rights and rights under (1) unless the express or tacit consent of the latter is obtained.

(3) The need for international cooperation through information sharing, consultation, joint programs and/or controls, possibly with licensing, to achieve beneficial use of the possibilities of controlling weather modification for the greatest benefit of all mankind and for sharing the costs and gains fairly. The forms cooperation will take should keep pace with knowledge and unfolding technological capabilities.

(4) The need for international cooperation among the affected states for effectively controlling pollution and the damages from inadvertent weather modification while assuring the right to pursue industrial development to all.

It is surely time now to think further about defining and achieving the optimal international institutional strategy for regulating the whole potential range of environmental modification activities to assure they are normally undertaken only in the common interests.

Some years ago we suggested, not hopefully, but not entirely facetiously, that, since the development of any capabilities to create major weather changes might be extraordinarily destabilizing in the current world system of order, that all such major international research projects in climate and weather as GARP, which are designed and intended to yield the information which would make a "weather weapon" much more of a real possibility, be postponed or halted until such time as the necessary actions to cope peacefully with these possibilities also seemed likely.

We can not realistically expect the scientific community to willingly give up such major quests for understanding. We therefore agree with the Subcommittee that international action of some sort to safeguard humanity from the dangerous potentials of such new knowledge is already appropriate. We feel, however, that the approach to large-scale weather modification should be more inclusive than that of the proposed treaty in ways already mentioned. We also feel that the treaty goes too far in other respects.

2. The proposal is too broad:

(a) There are several possible modification techniques which seem inappropriate for banning in part for humanitarian reasons at least so long as armed conflict by traditional weapons remains internationally lawful. The most obvious case is

<sup>11</sup> The "Industrialization-pollution" set is clearly very untractable without some modification of the currently typical actions of the actors in the international system. It is by no means impossible to think of approaches which would induce the developing states to cooperate to minimize world problems so long as they do not have to pay for this luxury.

<sup>12</sup> Since it may be scientifically the case that any modification effort may have some effect, however slight, on another (or on every other) country's weather resources, it should be made clear that this principle does not bar all activities. If an effect is minor and unintended, and can be readily and fully compensated for, it presumably should be tolerated. This principle makes it clear that damage must be avoided where possible and paid for where minor and inadvertent.