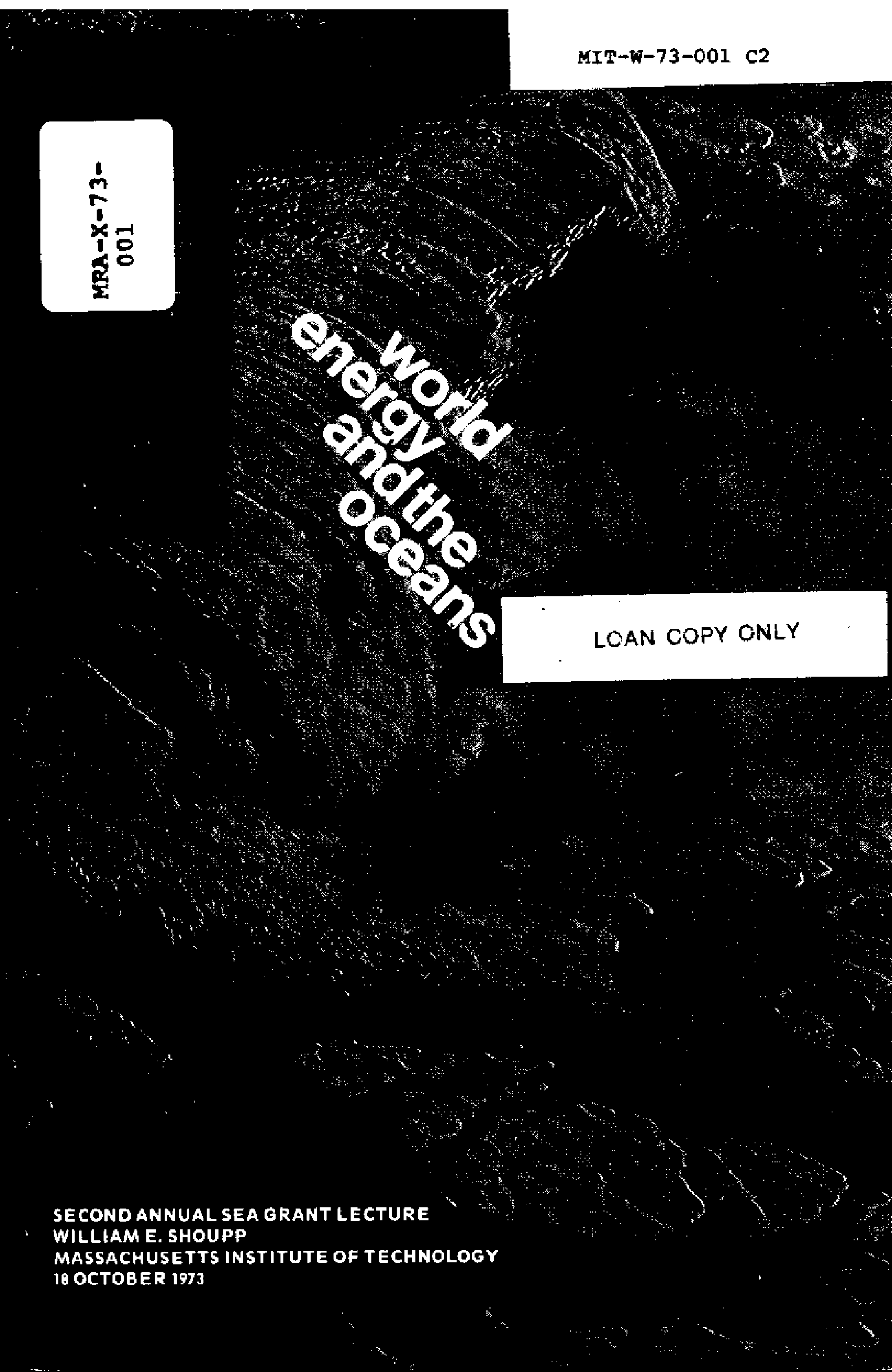

world energy and the oceans

SECOND ANNUAL SEA GRANT LECTURE

WILLIAM E. SHOUPP
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

18 OCTOBER 1973

Second Annual Sea Grant Lecture and Symposium

WORLD ENERGY AND THE OCEANS

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KEY ISSUES IN OFFSHORE OIL

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INNOVATIONS IN HEAT DISPOSAL IN THE OCEANS

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WORLD ENERGY AND THE OCEANS

Dr. William Earl Shoupp

It is indeed a great pleasure to be here with you on this occasion. I can see so many friends here, and the atmosphere and surroundings are so pleasant that it upsets me a bit to discuss the subject of my talk. If I were to choose arbitrarily two areas that would be the most difficult upon which to expound or even to discuss rationally, I would have difficulty finding two more opposite than resources and the ocean. Although the problems of resources, energy, the uses of the oceans, and the constraints thereon have been discussed extensively, these discussions have led many people to believe that the associated problems are virutally insoluble. I do not share this feeling, but I'll buy about two sigma of it. The combined topic, resources and the ocean, is distressing, but this may be our last chance to look at our past, present, and future actions and to develop ways of thinking rationally about our problems and trying to solve them. It is not too late, but our allowable time is disappearing rapidly. We need to act immediately.

Consider first the resources situation. I believe the public has been lulled to sleep during the last thirty years by the predictions of disaster relative to the availability of certain minerals, gas and liquid hydrocarbons. We have cried wolf in this area since 1936, but each time the wolf has not really been there. I am afraid, however, that now the wolf is outside the door sharpening his teeth.

I would like to discuss some of my opinions about energy resources and their conversion systems to usable energy forms. In each one I find the required action directly connected to the ocean. In the literature there exists a tendency to confuse energy resources and energy conversion systems and to regard them as completely interchangeable. They are interchangeable only if the form their output takes can be interchanged or substituted. This confusion leads to overemphasis of one vis-à-vis the other. As an example, even with more than reasonable technical progress, I do not see how MHD (magnetohydrodynamics), fuel cells, or other exotic conversion systems can contribute much to solving our energy problem on a useful time-scale. The potential percentage gain of these systems is just too small and their costs are much too high to give them much advantage over other systems. In addition, early models of alternate conversion schemes will require fuels we wish to conserve. A definite, but not extensive, funding level should be established and sustained for work on the limitations of such devices. But their potential contributions, even by 1985, can hardly warrant the costs of pilot or demonstration plant construction.

Nor should these systems command a large fraction of our Research and Development budget on energy or resource uses and conservation. The case is the same for some energy sources—for example, geothermal and solar—as it is for conversion methods. At present, many of the suggestions to utilize solar energy are out of bounds economically. Geothermal and solar energy may be and should be used. But I think they will not affect our economy significantly by 1985, and we should regard them as ancillary and severely limited by geographical distribution. They should be given some funding to increase chances for a major breakthrough, and if this occurs, the effort should be markedly increased immediately.

I, among many others, try to invent new solar energy devices, try to find ways of using this relatively nondepletable resource. But I believe we need to change our approach. Now most solar energy researchers tend toward higher efficiency solar cells or chlorophyll systems. The sun shines only part of the day, so solar cell systems need energy storage devices and inverters—both of which are presently expensive. Chlorophyll systems have "built-in" storage systems, but they need water. The best place to get hold of solar energy is the desert—hardly the place where one finds water easily. And I am sure that our valuable land where we have water will be used for other purposes. (Incidentally, some have published numbers on the land or forest area required to sustain large power plants. In recalculating them, I find most of them to be off by roughly a factor of ten in the wrong way.) I would think the best chance for solar energy conversion systems would be to place on the desert floor or on a substrate some materials to which the solar energy does something so that the material increases its energy content by increasing its chemical bonding energy. Such materials might be, for example, a deliquescent salt or a material such as lithium bromide or a cheap substitute thereof. This material may then be shipped just as coal is, to a power plant and used and reused at a much more advantageous site than the desert. This would avoid the energy storage and water problems, as well as the problem of long-distance electrical or thermal transmission and distribution. But these schemes do not get us out of our 1985 dilemma. What can we do?

Consider for the moment a truncated listing of energy forms and uses in order of their presently preferred use (most preferred are at top of table). We can see

Home Htg.	Home Mkg.	Cool-ing	Mat. & Procsg.	Autos	Urban Public Trans.	Trucks	R.R.	Indl. Htg.	Local Power Gen.	Center Sta.
Gas	El	El(U)	Gas	Oil	Oil	Oil	Oil	Gas	Gas	Gas
Oil	Gas	Gas	Oil	Gas	El	Gas	El	El(U)	Oil	Oil
El	Oil	Oil	Coal	El(U)	Gas	El	Coal	Oil	Coal	U
Coal	Coal	Coal	El(U)	Coal	Coal	Coal	Gas	Coal	U	Coal

how important gas and oil are to our economy. At this same price per BTU, it is obvious that for heating, gas would drive out oil, oil would drive out electricity, and electricity would drive out coal. What this really says is that gas is the number one fuel for heating, followed by oil and by other substitutes. Thus, for heating purposes, we should treat gas as the premium fuel it is, and we should always expect it to command a premium price in the marketplace. The reasons for preferring gas are obvious; its cleanliness and its established distribution capability from sources to users. Since gas may become our first scarce fuel as well as our premium fuel, substitutes for gas or the conversion of the other forms of fuel to make either gas or fuels that may be used in the same general system should be very high priority in our national effort. And substitutes for oil or the replenishment of the oil supply should be next. I emphasize that a substitute is necessary to fulfill the requirement of the existing fuel usage—not that the fuel itself had to be precisely synthetically reproduced. This replacement procedure of moving fuels from the bottom to the top of the chart—e.g., coal up to gas—then should proceed through the fuel materials chain as the chart indicates. This could become the format for deciding our national priorities for developmental programs for supplying our energy demands. If our solution is to increase the supply of oil and gas, the importance of the oil and gas reserves in the offshore areas, the uses of the ocean surface for transportation and its depths for its thermal properties for heat rejection are thus first priority.

Let us look briefly at some generally agreed upon numbers associated with energy supply and demand—although I am sure that everyone has his own provate set of information of this type. Most estimates of the total extractable amount of oil fuels in the free world are approximately 2×10^{12} barrels. At the present time the United States is using oil at about 40×10^{6} barrels per day, and we will probably be doubling this quantity by 1985. This then is about a fifty-year supply, not counting the shale oil or coal reserves and assuming the oil is freely distributed throughout the world. We certainly should expect tapering off of the usage near the end of the 50 years, because it will be then necessary to preserve some of the reserves for nonfuel purposes. I think that it is reasonable to expect more efficient usages, better control of oil usages, and alternate energy sources may allow us to hold the level at this projected 1985 oil consumption rate, that logic by that time will prevail upon us to do so. Many others do not believe our demand growth rate will slack off so they may also not agree with the statement on the fifty-year supply. But I believe we have at least this much oil as a world reserve—probably even more—as well as enough technology coming on to do something about the problem. That there seems to be abundant world supplies of oil does not at all assure us of domestic supplies at reasonable prices. What then are our domestic recourses?

Much of the price we now pay for mid-East oil is a tax or as costs unassociated with the production effort. But the U.S. oil industry sources must be developed further before we can exert much influence on the price of imported oil. Now the wellhead cost of Middle East production varies from about 15 cents to one dollar a barrel. By the time the taxes are collected, and the oils arrive on our coast, the price is between four and five dollars. Some of this difference arises from shipping and handling, but much of it is unconnected with production costs. And it now looks as though taxes will soon be increased. Our only recourses, therefore, are to increase our own petroleum supply or to develop an alternate supply of oil or its equivalent before we can expect to drive down the price of petroleum products. Prices will rise until they interfere with the net profit of the producing body. This is just a fact of business life. As a country, we infrequently exert such pressures as are being put on us in the present petroleum rat race. For example, we have not held up the world in the price of our exported foodstuffs. And even in the case of energy resources, our prices for such things as enriched uranium and low sulfur coal do not seem to me to have been exorbitantly priced. I believe it would be interesting for us to examine our policies in such matters, to learn how to effectively exert economic pressures in the supply of our products—but that is another matter best dealt with elsewhere. The important question is—How long do we have to develop ways and means to establish the necessary countervailing forces, both economic and alternate sources, to overcome our energy resource crunch? Already we have used a lot of time without much apparent success. If we continue at our present rate of progress, I am afraid that we may be licked before we get started.

For the United States, development and demonstration of alternate fuel supplies that substitute economically for oil and gas is a challenge, but not an impossible one if we attack it with appropriate industrial vigor, financial support, and government encouragement and behave as our competition does: as a united cohesive force. Despite all the talking we've heard recently, we do not have substitution research programs sufficiently strong to worry the wolf who is really at the door.

In his recent energy message, the President has clearly recognized our society's soaring demands for energy. In his message, the President emphasized conservation needs, but also possibilities of our use of coal and of locating and using our potential oil and gas reserves. I have formally supported him in this pronouncement. However, the location, or even the beginning of exploration to locate oil and gas reserves off the eastern continental slopes and shelves will take much time and effort and will be delayed for at least a year while an environmental impact survey is made—and presumably longer for subsequent evaluation and argument.

It takes a long time to find oil or gas and an even longer time to build refineries and to process oil and gas into products. While general criteria may be developed about oil or gas site development, impact statements tend to be specific and definitive about the location under consideration; they may even be dependent upon the extent and type of energy resources to be supplied. This, in turn, is dependent on the specific geology, population, local conditions, and alternate uses.

I submit (1) that preparing a generalized, nonspecific impact statement may be desirable, but that it delays the potential exploration and thus the utilization by more than the year that it will take to prepare, and (2) that in any event it will have to be done all over again, as a definitive, specific statement when and if oil or gas reserves are discovered and precisely located along the East Coast, in Channel Islands, or in the Gulf of Alaska. When we know we should have and must use these possible resources, why we tolerate the slowdown of exploration and investigation of our resources by such time-consuming exercises is beyond me. I favor requiring environmental impact statements for large or hazardous installations, but generalized impact statements for the whole East Coast, the areas beyond the Channel Islands, and the Gulf of Alaska appear to me to be specious and frivolous, for they could instead be done in parallel with detailed major exploration programs. The important thing is to get on with evaluating and finding our resources and preparing to utilize those it seems logical to utilize while we simultaneously evaluate the national trade-offs and environmental impact analysis and prepare cost / benefit analyses.

We must realize we cannot have something for nothing; we must be ready to share the inconveniences caused by developing and using resources for the benefit of all the national community. We must each share in any losses of conveniences to obtain the benefits for ourselves and others if we expect them to do the same for us. Just as the practice of keeping oil and gas resources in a particular state, county, or farm is hardly realistic because one has to trade some of them to get manufactured or agricultural products for one's own use, neither is it realistic to make rules that require zero impact or any type of disturbances—be they visual, aromatic, or audible—for the sake of oneself or a limited few. One must evaluate situations like this reasonably for the overall national good, recognizing that anything one does will affect others.

I believe a dynamic exploration program would uncover within our own ocean shelves and slopes, a lot more hydrocarbon fossil fuel reserves than we now expect to find. Certainly by the time we discover them, the technology will be available to utilize these fuels without damaging the environment. Having these reserves and the capability to utilize them may even allow us to conserve them, perhaps even never to use them. They could then be a national asset for emergencies or use under circumstances we do not anticipate now. This would mean ownership of the reserves and some of the equipment for utilization would probably have to be at least temporarily with government, which would turn them over to private industry only when they are to be used.

If fuel reserves and the capability to use them existed and could be pointed to, I believe the price that we are now paying for our energy products elsewhere would more nearly reach a level that would bear some relation to their cost. I also believe that to have this reserve utilization capability is the only way we can reduce the cost. We will still use mid-East oil extensively, but I believe that the price will then be more realistic and we will be able to stockpile and to limit use of our own reserves. In this kind of negotiation, it is not enough to threaten someone that you will develop another energy system if his price isn't right for what you are buying. You must also prove you can do it, be able to point to your alternate and say "I will use this if you don't better the price." For the United States, the most likely solution is developing our offshore oil reserves.

But regardless of the status of our own resources, shipping mid-East oil will require constructing offshore ports and mooring systems, as well as massive transportation, refinery and distribution facilities. I am astonished that we are still talking and doing little for the offshore systems we will require, that we are allowing a few objectors to delay action on something that is so important to the nation. If over 55 percent of the people in the United States live within 50 miles of the coast, some estimate this is likely to be 75 percent by 1985, I believe that with this population increase should go provision for supplying these people's needs; among them will be lots of low-cost energy near the coast. This will involve developing and supplying various energy forms and social amenities that are energy dependent. It is best that as much as possible of this energy supply be located as near as possible to the population it serves—along the coast or on, or within, the sea. If we really were to implement a program like this and to pursue it vigorously, we would by 1985 still be supplying only a portion of our oil demands. However, Professor Morris Adelman here at M.I.T. is at least partly correct that the leverage the U.S. would gain by reducing even by a fraction its enormous mid-East oil consumption would probably be sufficient to cause both a more rational pricing policy and greater product availability.

I believe, therefore, that we should emphasize the following action programs:

1. The first and most important program is to locate, to evaluate, and to begin to utilize additional reserves, whether they be in Alaska, off the east coast, off the west coast, or in the Gulf of Mexico. Much of this utilization will, in deep water, require bottom-mounted wellhead completion systems. There are two major efforts for such systems, and it is interesting to note that foreign financing as well as industrial monies are used to support these efforts and that our govern-

ment is not substantially involved. I think it is strange that while other countries recognize the value of deep-water completion systems and are willing to invest their monies in these developments, the U.S. government, which should have the greatest interest and the most to gain, is not adequately supporting this kind of developmental work. U.S. industry is instead doing most of the work in this field in association with foreign industry and foreign governments.

2. We should remove the nonessential constraints that limit construction and operation of atomic power plants to shorten the time from conception to full power operation from ten-twelve years to five or six years. This will decrease our dependence on oil and gas for electric power generation, and it will buy us time and ensure our ability to use the enlarging electric economy as it further develops. In addition, we must expedite the nuclear breeder reactor projects as much as possible to ensure the longer range competence of our electric energy supply.

Thus we should also expand our ability to construct and use atomic power plants, both converters and breeders, for although by 1985 the fraction of electrical energy nuclear power can be expected to produce is relatively small, the leverage may be large. I think it is tacitly ridiculous for us to impose unnecessary constraints on construction and operation of atomic power plants, since they have fully demonstrated themselves to be good neighbors and have outstanding safety records. If we were to undertake a massive national program to increase construction of atomic power plants, the contributions to the energy situation could be significant even by 1985.

3. Since increased construction of utility power plants will have a difficult time technically in supplying the energy required to operate automobiles and transport systems by 1985, we must increase our technical capability in substituting electric power for more than current uses, because electricity can be supplied by nuclear rather than fossil power. This probably includes electricity for your second or third car, although certainly progress in battery R&D does not appear capable now of providing for your number one car. Local and urban transportation, however, is entirely different. I believe electricity, through the use of advanced-type batteries, as well as trolley or combination electrical systems, can provide the urban transportation for much of big cities mass transit needs and ancillary uses. And we should utilize reject heat from electric utility plants for space heating and process steam, as do most other countries. Therefore, we should expedite construction of electric utility plants, and at least some of these should be constructed in such size and at locations such that the reject heat can be used through a combination of thermal pipelines and large heat pumps. It is absurd to suggest that the long-term solution to our energy problems is to use less energy. This is unrealistic because as civilization develops and as our mineral, agricultural, and other resources become more diluted and depleted, it will take more energy per capita, not less, to sustain any sort of civilization with which we are familiar. We should take steps to conserve, not to waste, energy; but as we necessarily obtain our materials from increasingly depleted resources, and as we try to improve our environment, we will require more energy, not less.

4. Since we will require many more large electric power generating stations, it is obvious to me that the logical coolant for large nuclear power plants is the ocean, and thus the logical location for such plants is, wherever possible, in large power-demand centers near, on, or in the ocean. There is no question of the technical feasibility or operability of atomic power plants in the ocean environment, since we have many naval ships with reactors aboard in full service with exceptionally fine service records. Objection without an equivalent alternate solution to such a program is strictly obstructionism and with our present energy situation we would do better with less obstructionism to the actions that are necessary to meet our needs.

5. We must remember, when we consider the applicability of alternate energy sources, it is necessary to consider the convertibility of one form of energy into another, since if this is not possible, the substitution aspects may control which aspects we should concentrate on developing. As our technology increases, electricity is becoming increasingly substitutable for other forms of energy. Battery developments, thermal pipelines, large heat pumps, and inverse heat pumps all promise a capability of increasing substitution of electrical energy for other sources. This additionally emphasizes the necessity of a speed-up in our construction of electric generation capabilities.

6. Coal gasification systems are large and expensive, but they are not heavy polluters. The process can even extract the sulfur from high sulfur coal and deliver either low BTU gas relatively inexpensively, or feedstock for methane production for pipelines. Developing and constructing full-size demonstration plants for both coal gas and methane are necessary, but they are an important third in my priority list. As a variant of very large systems which have been adequately described in the literature, consider combining a coal gasification plant with a combined cycle utility electric generation system. We are generally considering the generation of electricity in small plants and the use of the reject heat in an individual home or in a small group of homes. I believe that it is perfectly feasible to put high-efficiency electric generating stations in the downtown or urban areas that use gas from coal gasification as their energy source. It may or may not be feasible to have the coal gasification plant built integrally with the power plant, but this is not important.

What does this do for you? Since the gas generated in the "town gas" reaction is a low-heat content gas (about 150 BTU per cubic foot), it is necessary to locate the gasification plant nearby, within the economic range of being able to pipe it economically to the urban power plant (zero to a few miles). If the power plant is actually downtown, it will have another advantage. Many major coastal cities are built on rivers, oceans, or lakes. This was for transportation, but it now also provides a natural source for disposing of the reject heat from a power plant like this. Under this plan, however, the reject heat can be greatly reduced if we now use much of it in the coastal cities—for heating and cooling buildings and certain cases, for process heat and process steam uses, for example. The use of two-phase pipelines from an urban power station are probably economic over a distance of two to five miles. Generally this is sufficient because the type of power plant I am talking about is a combined cycle plant, such as a PACE plant whose size is usually in the 100 to 300 megawatt-electric range. Such combined cycle plants will be made to have an efficiency in the 50-55 percent range, and by using reject heat, as little as one quarter to one third of the energy need be dissipated through the reject heat system. This differs greatly from present practice in the United States; our country seems to be one of the few that does not take advantage of some sort of heat recovery system. I maintain that combined cycle plants are good neighbors and belong downtown, and that we cannot afford to throw away even the relatively small amount of heat these high-efficiency plants reject. Downtown will often be on the ocean, on a lake, or on a large river. The coal gasification program, with an associated methanation or methanolization program must have high priority for our national developmental needs.

7. We have all heard much of the proposed hydrogen economy. On this subjet my opinions diverge from most. I believe strongly in coal gasification, particularly for further development of the town gas reaction, in which a mixture of carbon monoxide and hydrogen with some heat methane is produced. By shifting the pressures around in this reaction and possibly adding a bit more hydrogen, possibly obtained electrolytically, one can make methanol from this gaseous mixture. Methanol is a very interesting fuel. Although it is twice as heavy per unit of energy output when burned in most engines, it also produces only a third as much nitrous oxide and roughly 10 percent of the carbon monoxide that gasoline does when burned in the standard vehicle engine. It is probable that the energy efficiency of coal to methanol conversion process could be in the 60-70 percent—which not only makes it economic, but produces a highly diverse multipurpose fuel because of the available feedstocks used. Methanol is virtually a universal and an almost ideal fuel. It is clean. It can be piped to your home more easily than gas. It can be burned in your car as a replacement for gasoline or an additive or supplement to petroleum products. It can be used as a fuel for local power of heat production in advanced fuel cells, since it may be stored in tanks as a liquid or piped around the city like gas. It is certainly safer to handle than gas, gasoline, LNG, or most other fuel products. The methanol economy should be considered as an important spinoff from the coal gasification effort.

The methanol economy and the clean smaller urban electric plant, the combined cycle coal gas plant, and greatly expanded nuclear power plant usage, both converters and breeders, for the larger base load plants and located in larger energy depots, are the ways to supply our future electrical energy needs. The large base load plants should, wherever possible, be located upon or within the ocean. Where else can we find such a good heat sink. The ecological effects from such a system would, I believe, have the favorable benefit to cost ratios.

8. There are additional alternate energy sources we should consider. One of these is ethanol. It is possible to extract 300 pounds of ethanol from a ton of average trash and garbage from which the metal has already been removed. This is an extension of the winemaker's art and has been shown that considerably more ethanol can be converted from cellulose and similar products that we had thought previously. An analysis of the quantities involved show that conversion process like this could probably supply the energy demands of the public urban transportation systems within the city from its own waste products. Although this is a relatively small national energy contribution, it takes care of two problems: it gets rid of the trash and garbage, and it provides a reasonably sized source of fuel. This is a program we should pursue, but it is not as important as coal gasification.

We should remember that the several development programs I mention would require massive infusion of dollars, manpower, and natural resources; they are not to be toyed with in terms of just tens or even a few hundred million dollars for research, development, and plant demonstration costs. These very high costs mean concentrating on a few programs and assuming the risks of costly failure of some of them. We are in a multibillion dollar difficulty, and it is going to be costly to get out of it. I don't think we can afford to risk solutions to our near-term problems by depending upon new basic concepts or concentrating on long-term highly speculative research and development. I love new ideas and they are much more fun to work on, but we are in a crisis situation, and we need most urgently to fully develop and bring to fruition some of the ideas we already have. New ideas certainly are needed and always welcome, but at the moment, with our impending energy crunch, they should take a secondary role. The apparently limited development money available must be concentrated on a relatively few specific projects, and these must be pushed to early implementation, completion, or abandonment. We must take some risks and accept some failures. The solution to our energy problems for the next fifty years will not come easily and will not wait for nuclear fusion or other exotic solution; they will require concentrating efforts on a few major programs carried through full-scale plant implementation. However, long-range programs of high potential should be assured of a relatively constant effort level until we resolve our existing energy crisis.

So, I call not for words and threats but for action on locating our offshore reserves and maximizing use of our ocean for its fuel resources, for fuel transport, and for sites for our large new power plants and superports. I ask for increased effort in developing ways of converting our coal reserves into gas and liquid fuels and for a more intensive switch to the electric economy. I call for more efficient uses of more energy—not less. And these uses must benefit our economy and our ecology. That is the way to the future. We cannot retreat to the Garden of Eden, because we've already eaten the apple.

Let's get on with it!

KEY ISSUES IN OFFSHORE OIL

Dr. John W. Devanney III

Offshore petroleum is my subject. M.I.T. has only recently become involved in offshore oil, at least insofar as direct applications are concerned. Fay, Hoult, and Milgram did pioneering work in oil spill spreading and containment at M.I.T. six or seven years ago. M.I.T. has also had long-term interest in certain theoretical problems relating to offshore oil: wave forces on fixed structures are an example. But our direct involvement in offshore oil began in 1972 with the Georges Bank Petroleum Study.

The Georges Bank Study was sponsored jointly by Sea Grant, the New England Regional Commission and the New England River Basins Commission. The study generated estimates of the change in real New England income and regional environmental quality associated with a range of hypothetical petroleum developments on Georges Bank (Fig. 1). This study afforded us the first real opportunity to study offshore oil. I believe it has also served to identify several important issues with respect to offshore oil about which the quality of debate in the United States ranges from poor to nonexistent. I would like to discuss some of these with you today.

The environmental aspect of the Georges Bank analyses involved:

1. a survey of the literature to the biological effect of oil, particularly the toxicity;
2. an analysis of how long a Georges Bank oil spill would be likely to stay on the Bank and where it would be likely to go;
3. an investigation of available oil spill statistics and an estimate of the change in the amount of oil which would be spilled in New England under a number of development hypotheses;
4. a preliminary analysis of the hydrocarbon plumes emanating from oil water separator discharges and refinery wastewater outfalls;
5. worst-case analyses of both the fish larval kill possible from a spill and the fishing boat-platform conflict; and
6. a rough study of the loss in regional income associated with nearshore spillage as a result of clean-up, loss in recreational opportunities, and loss in tourism.

It is important to realize that oil is a mixture of a large number of compounds. The toxicity of these compounds varies by several orders of magnitude. Our survey of the available biological data has convinced us that certain of these compounds are responsible for the bulk of the biological damage. With crude oil, we believe the culprits to be the soluble aromatics.

If this is true, then the proper focus of our environmental studies becomes the lighter aromatics. A number of obvious and important questions arise immediately. How fast do the aromatics leave the slick? How much evaporates into the air? How much is dissolved into the water column? What is the vertical distribution of these dissolved compounds and how much gets into the sediments? Scientists know that the bulk of these compounds leave the slick within a day or two. But just how much dissolves into the water, and how quickly, is a matter of conjecture.

We are currently attacking this problem through a combined theoretical and experimental program. The theoretical analyses (Fig. 2) involve modeling and solving the vertical evaporation and diffusion process shown. The solution of these diffusion problems, in addition to involving some rather sophisticated computa-

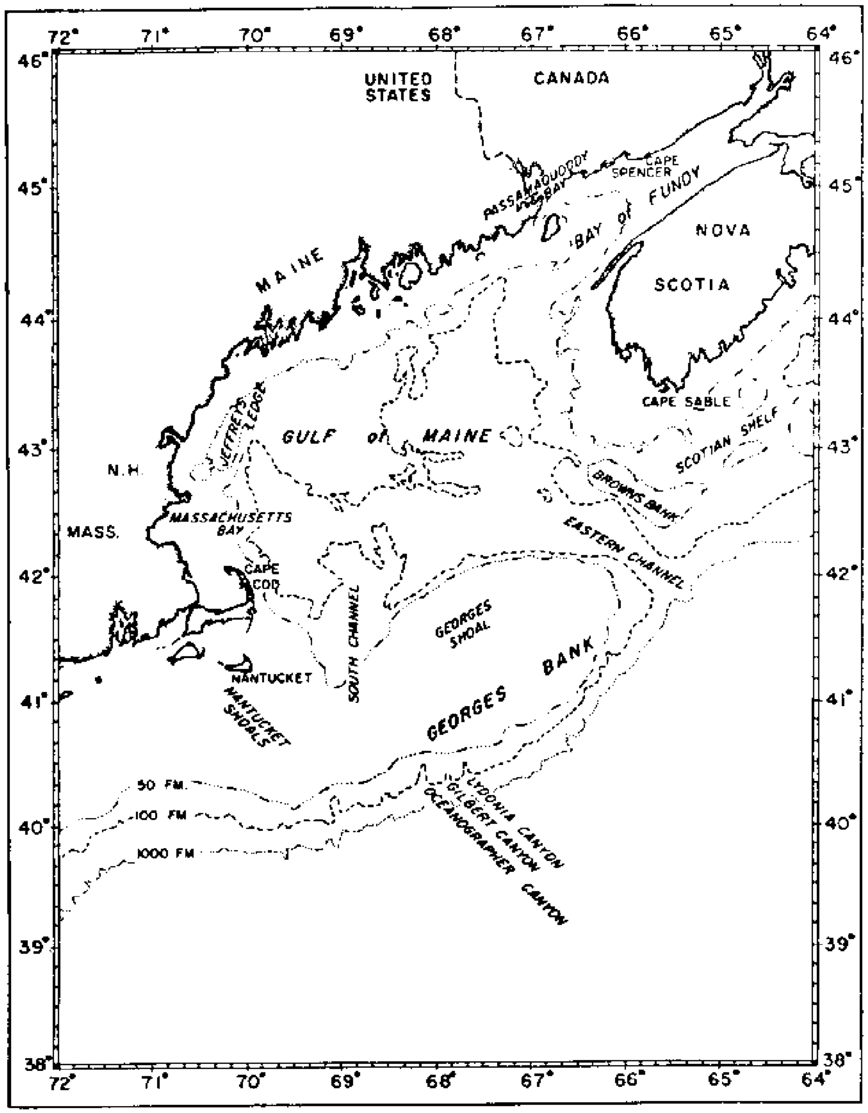

Fig. 1. Orientation chart of the Gulf of Maine (Colton, 1964).

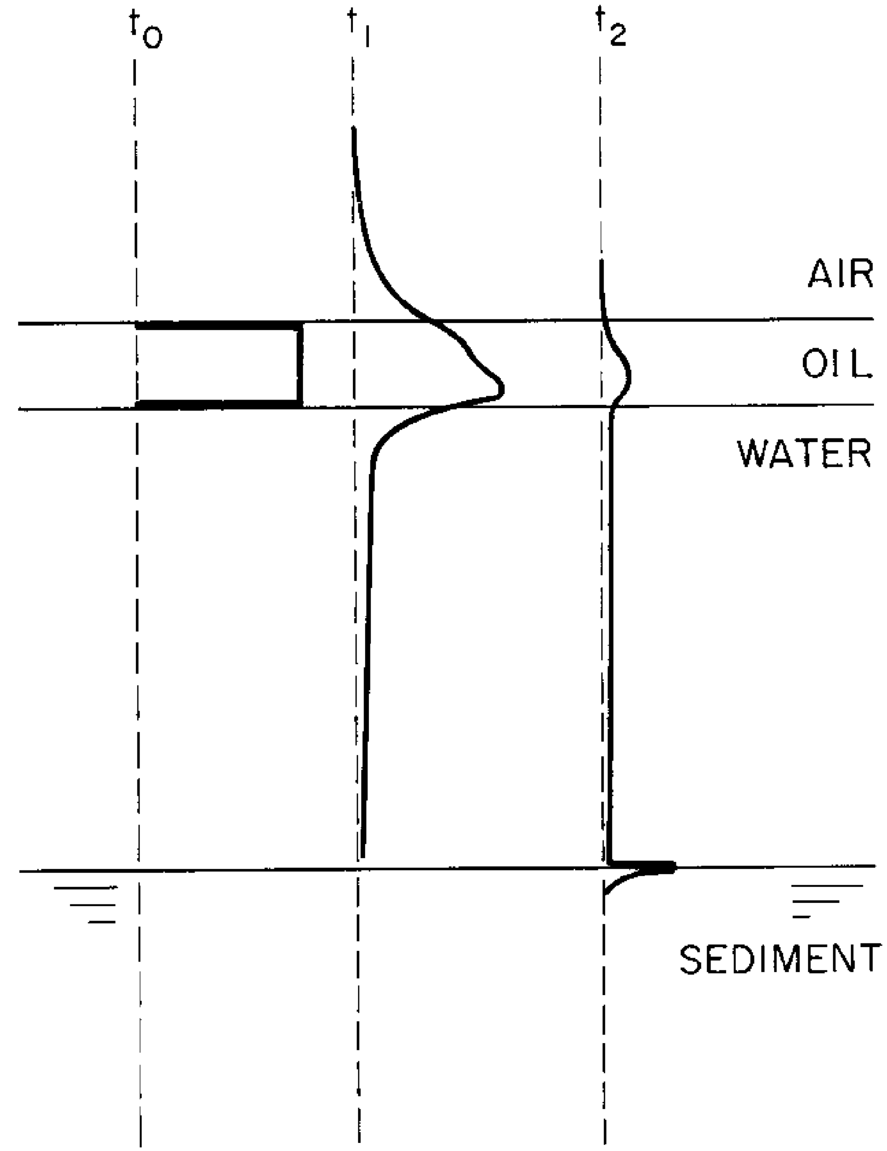

Fig. 2. Vertical evaporation and dissolution studies.

tional techniques (which means sometimes we can get them to work and sometimes we cannot) also requires knowledge of several parameters of this process which we are going after experimentally. (The equipment we are using to measure the results of these experiments was originally developed to analyze soil samples on Mars.) If all goes well, the preliminary results of these studies should begin to become available at the end of 1973.

Vis-à-vis the spreading and transport of spills, the Georges Bank analysis indicated that, because of the strong westerly component to the winds on the North Atlantic coast, it is highly unlikely that a winter spill on Georges Bank will ever reach shore, and perhaps 5 percent of the summer spills will come ashore. Those that do come ashore will take over a month and as a result will be very well weathered. We expect no shoreline biological damage from these spills.[1] Further, our studies of the larval fish kill which could result from a large spill on the Bank showed insignificant kill levels, essentially because the spawning area and season of even the most concentrated species is sufficiently diffuse that it is impossible for a single spill to affect more than a very small proportion of the year class (Fig. 3). Our study of the area denied the fishermen as a result of the platforms associated with a large find on the Bank also failed to yield substantial economic losses.

As a result of these findings, we began focusing more and more on the nearshore spill (Fig. 4). We expect the nearshore spill to be much more damaging than an equivalent far-offshore spill for a number of reasons: (1) the littoral zone is characterized by extremely high productivity and relatively immobile species; (2) a nearshore spill will come ashore fresh, allowing substantial concentrations of the more toxic compounds to be attained in shoreline waters; (3) the relatively shallow waters and surf make it possible for a substantial portion of this oil to get into the sediments; and (4) the trapping effect of enbayments further aggravates the problem. As Figures 3 and 4 indicate, a nearshore spill is a hell of a lot "bigger" than the same spill far offshore.

One result of these conclusions is that we have recently become intrigued with the detailed behavior of a spill on the surface in the first few hours of the spill's life (Fig. 5). It is an experimental fact that oil does not spread as a single homogeneous liquid; rather, it appears to fractionate on the surface. Often this phenomenon takes the form of a single central "glob" whose thickness is of the order of millimeters or more surrounded by a "film" whose thickness is of the order of thousandths of a millimeter. The glob contains perhaps 90-95 percent of the oil and spreads much more slowly than the film, which occupies much more area than the glob. Sometimes the phenomenon takes the form of a number of individual globs, each surrounded by its own film. When dispersant is added to the film, still more complicated phenomena are observed. This surface fractionation is important to the spill problem for a number of reasons:

1. Whether or not the compounds in the film are the low surface tension, highly soluble constituents, as we suspect, will make a great difference in the time history of the concentrations of these toxic compounds that the biota in the water column will face. We are currently conducting tests with the Coast Guard to determine which compounds in the oil are in the film and which are in the glob. Notice that from the viewpoints of recreational amenities, tourism and shorefront propoerty values, the glob is what is important. For the biota, it may very well be

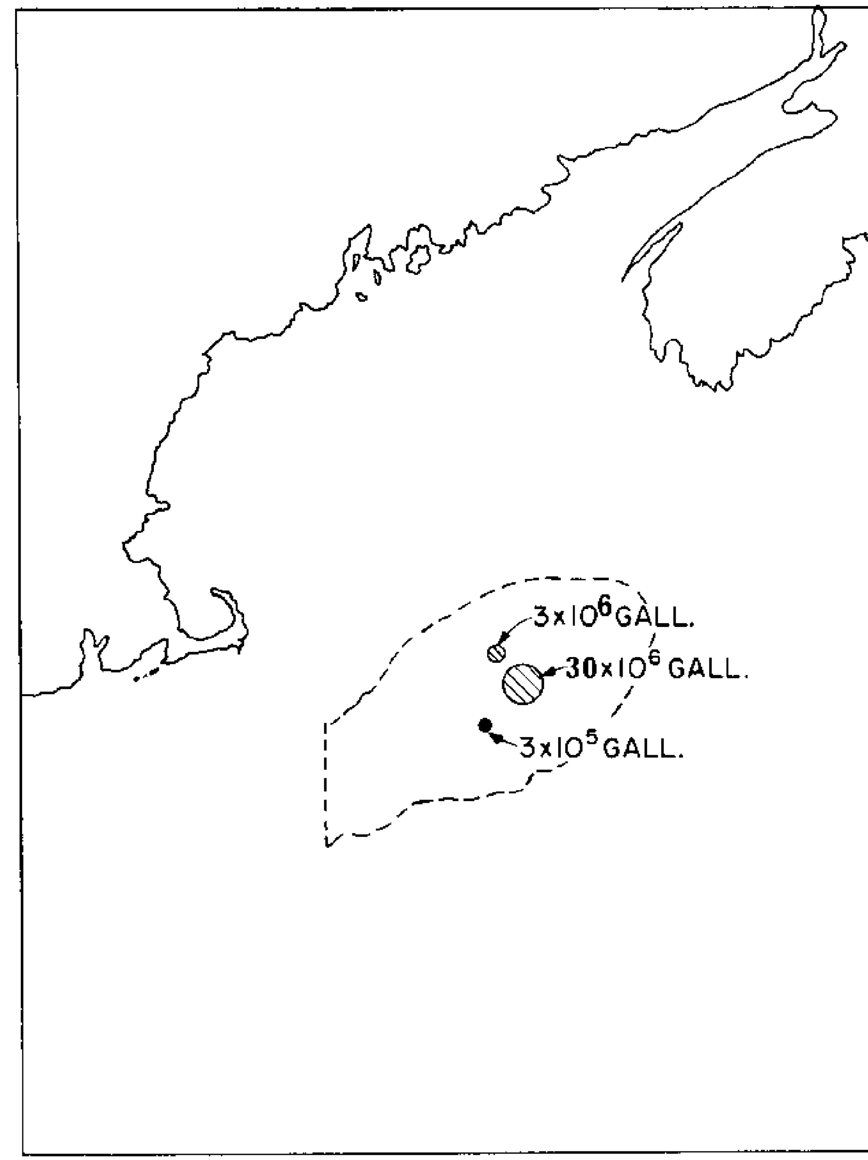

Fig. 3. Example of the areal extent of spills after spreading ceases.

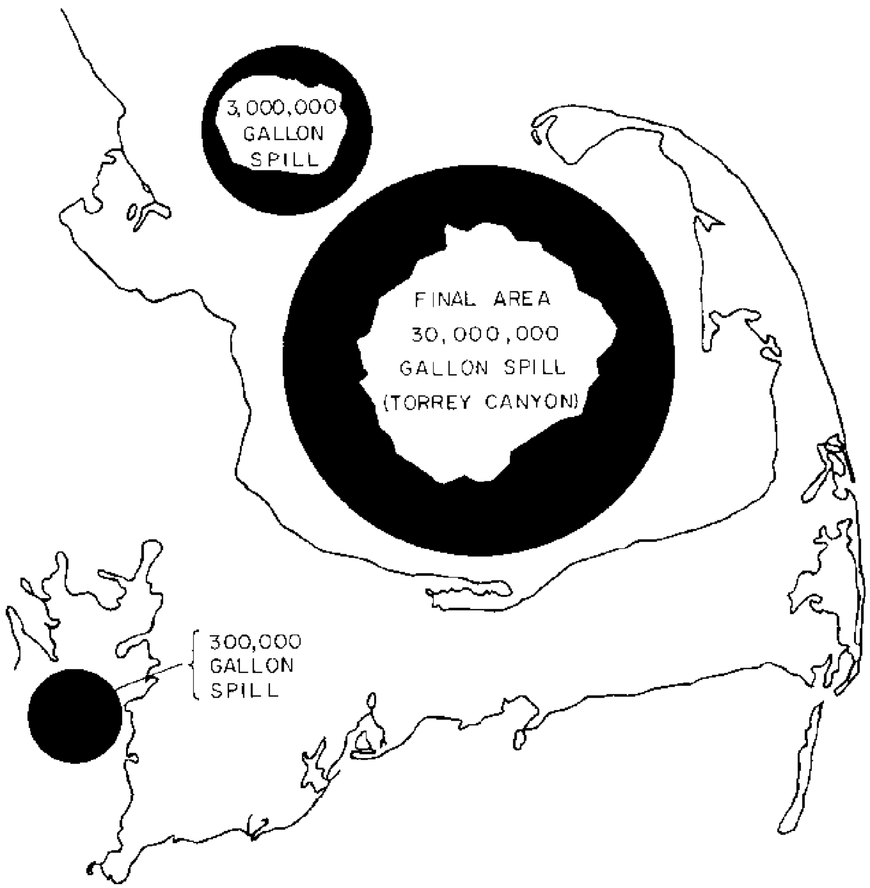

Fig. 4. Examples of the areal extent of spills after spreading ceases.

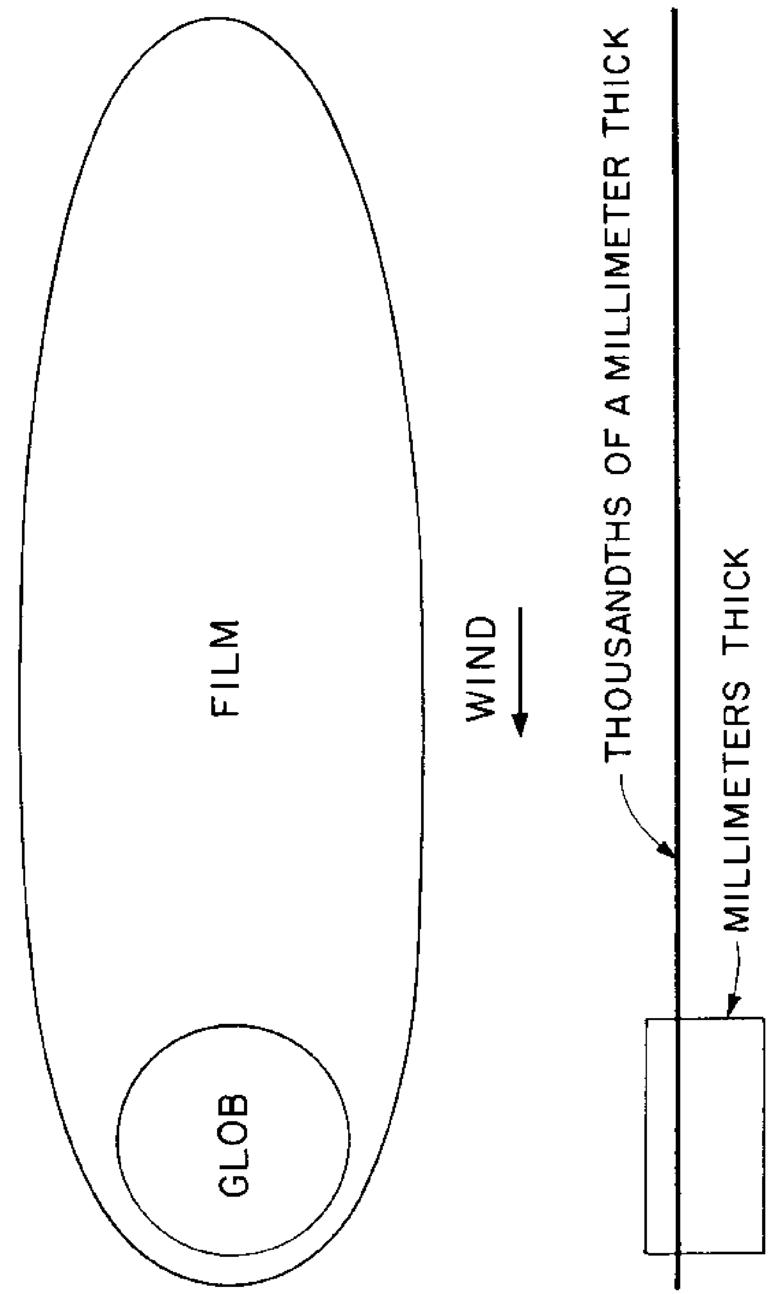

Fig. 5. Schematic of surface fractionation.

the film. In the oil spill game we often see a disparity between biological and esthetic values.

2. The weathering that results from this fractionation can be expected to be quite different from the weathering which would occur in its absence. This differential in weathering will feed back on the further behavior of the slick by affecting surface tension and viscosity. This, in turn will affect the design of containment and collection systems. Obviously it makes a great deal of difference to the design of these systems whether you are going after the glob, the film, or both.

3. We believe that the fractionation process presents us with important clues as to the manner in which the oil is transported by the wind. Invariably, the glob travels downwind slightly faster that the film. This suggests that the primary transport mechanism is not the wind directly but rather the damping of the wind-generated waves by the oil. We are currently undertaking a series of experiments in Professor Jerome Milgram's Precision Wave Tank to confirm or deny this conjecture.

I am not going to go into our analyses of oil spill statistics and hydrocarbon plumes except to make two fundamental points:

1. The greatest bulk of all the oil spilled is spilled in a few large spills. For example, the "Torrey Canyon" spilled twice as much oil as all the oil which was reported spilled in the United States in 1970, and two thirds of the oil spilled in the United States that year was spilled in three spills. If society is worried about the total amount of oil that's getting into the ocean through spills, the proper focus should be on decreasing the probability of the very large spill.

2. If, on the other hand, society is sincerely worried about the biota and accepts our suggestion that it is certain, very specific components in the oil which represent the biological danger, then much current regulation is misdirected. For example, refinery wastewater and oil/water separator discharge water is regulated for its total oil content. Industry presently meets these regulations primarily through gravity separation. Gravity separation has almost no effect on the amount of dissolved hydrocarbons in the discharge. Yet it is precisely these dissolved compounds which we believe are biologically critical. Society may presently be paying a high price for efforts devoted to separation to obtain practically no change in the biological effect of the discharged waters.

The economic analyses we undertook in the Georges Bank study also brought out some important points. One of the principle subtasks of the Georges Bank Study was construction of an offshore petroleum development model (Fig. 6). This computer program takes as input a number of geological variables describing an offshore find: e.g., oil in place, gas in place, type of reservoir drive, number of fields, permeability, porosity. The input includes variables describing the location of the find, the location of the shoreside terminal, water depth, design wave height, draft limitations at terminal, and finally a number of financial and regulatory variables, including landed oil and gas prices, lease and royalty rules, cost of capital, and allowables. The program includes a reservoir model which describes the stipulated reservoir's physical response to a particular development strategy through time. The computer examines a large number of combinations of production schedule and transportation system including a range of tankers and a range of pipelines and chooses that development strategy (number of platforms, number of wells, amount of reinjection) and that transport system which

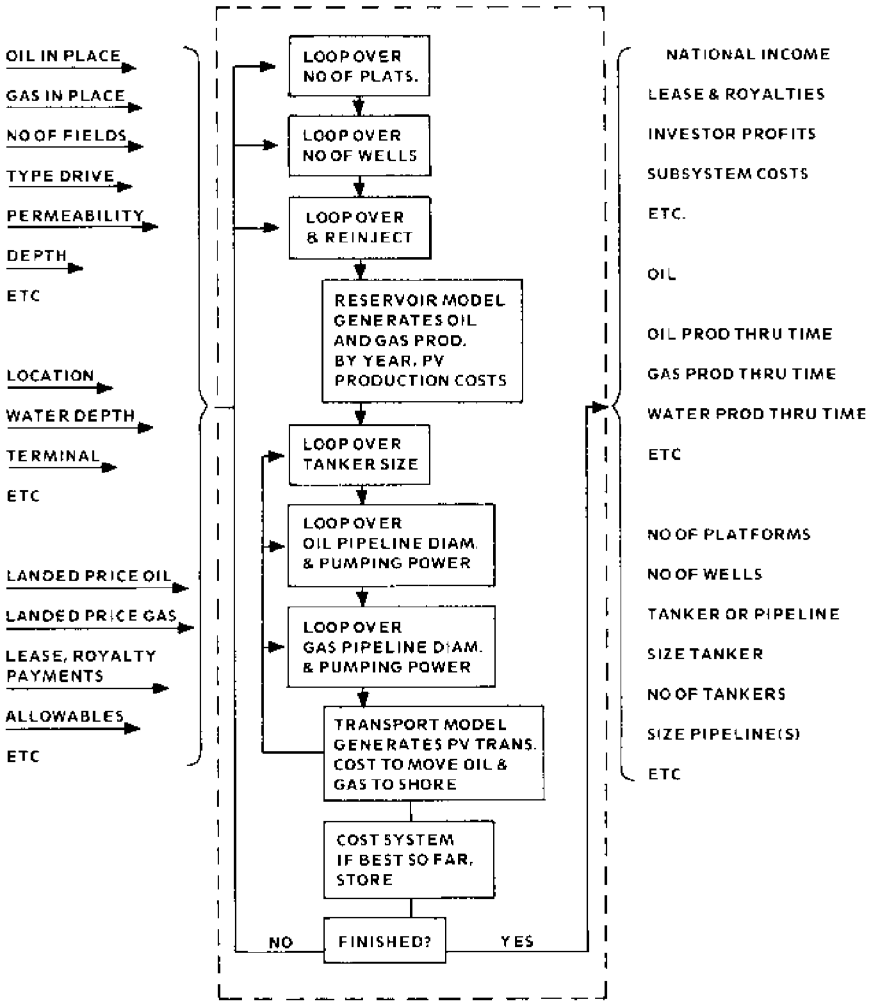

Fig. 6. Offshore development program.

maximize the investor's profits.

Since we first did the Georges Bank Study, we have been continually refining this program. We now have the capability to handle gas reinjection and artificial lift, and we have significantly improved our well bore loss model. Soon we will be able to handle certain water drives, and we are presently working on improving our platform construction cost model.

For my paper today, I don't need these refinements. Fig. 7 shows some of our earlier results. According to our calculations, oil from even a moderately sized find on the Atlantic continental shelf could be landed at a cost to the nation before lease payments, royalties, taxes, and profits of about one dollar per barrel. Various industry people have examined results such as these and some say they are a little high, some say a little low, so we know they are about right. Similarly, we find that associated gas from a moderately sized find could be landed at a national cost of about 20 cents / million cubic feet.

When one compares these figures with the three dollars, four dollars, and higher that we are now paying for foreign crude oil and one dollar or so we are paying for imported gas, one quickly comes to the conclusion that offshore petroleum can be quite cheap. It may not be particularly cheap compared with the resource cost of foreign crude oil (about 20 cents f.o.b. Persian Gulf plus 90 cents or so transport by deepdraft tanker), but as long as we are paying the exporting countries three dollars or more for the privilege of consuming this oil, the loss in real national income for each recoverable barrel of domestic offshore oil which is not developed will be in excess of three dollars per barrel.

Similar arguments hold for gas. For example, depending on whose estimates you believe, and depending on how fast the price of oil rises, the loss in national income associated with not exploiting the Atlantic continental shelf could easily run into the tens of billions of dollars, before adjustment for environmental costs.

This, then, is the first major point which the Georges Bank study makes: assuming no effective counter to the OPEC (Organization of Petroleum Exporting Countries) cartel develops, offshore petroleum can be cheap and the loss in real-national income associated with not exploiting domestic offshore resources quite sizable.

Leaving aside environmental problems for the moment, it is interesting to examine where the increase in national income associated with domestic offshore oil will show up. Here agin, the Georges Bank Study had an extremely important point to make. If we assume competition in the oil markets and no effective counter to OPEC develops, even the extensive exploitation of our offshore resources will have no effect on the market price of oil. The reason is simple: under competition, market price is determined by the most expensive unit of oil consumed. It is extremely unlikely that we can find enough offshore oil to force all foreign oil off the domestic market. Thus, price will still be determined by the expensive foreign oil. Assuming gas price deregulation, the same thing holds for gas.

If this is the case, where then will the savings in national income show up?

They will show up in lease and royalties payments, taxes, and investor profits which would not occur if the find had not been exploited. In fact, if the government does as good a job in leasing as our analysis indicates it had up to 1971, the bulk of the increase in national income will show up in the lease and royalty payments.

	REGION CONTROLS BANK		FEDS CONTROL BANK	
	GAS REG	GAS DEREG	GAS REG	GAS DEREG
INCREASE IN NATIONAL INCOME	+5.01	+5.01	+5.01	+5.01
INCREASE IN REGIONAL INCOME	+4.50	+4.13	+2.28	+ .42

ASSUMPTIONS. . $4.00 FOREIGN OIL (F.O.B.)

ALL FIGURES PRESENT VALUED AT 8 REAL

GAS SOLUTION DRIVE, 5 FIELDS

NO REINJECTION, REFINERY IN DELAWARE

OIL RECOVERY 14.7 , GAS RECOVERY 67.3

NO ENVIRONMENTAL COSTS

Fig. 7. Changes in national and New England income associated with exploiting a ten billion barrel, ten trillion cubic ft. (in place) find on the Georges Bank (billions of 1971 dollars).

These revenues, in turn, imply that the federal taxpayer will have to pay less for public services or, equivalently, we can have more public services for the same tax levels.

The point here is that the bulk of the increase in national income associated with offshore development is spread over the country in a rather invisible fashion—a tax break which would not otherwise happen. A portion of the increase will show up in the hands of oil company shareholders. This is also spread over the entire country.

On the other hand, the environmental disbenefits of offshore oil are localized in the immediate vicinity of the development in a highly visible manner. This to me is one of the primary problems facing offshore oil today. The economic benefits of a development are spread across the entire country; the environmental disbenefits are highly localized.

Let me give you one example from the Georges Bank Study. Fig. 7 indicates that five billion dollars is the present valued increase in national income associated with exploiting a hypothesized large find on the Georges Bank; this is the equivalent to handing each person in the U.S. 25 dollars worth of consumption on a one-shot basis. This increase in national income is independent of whether or not the federal government or regional governments receive the lease and royalty payments, and it is also independent of whether or not gas prices are decontrolled. However, New England's share of the increase in national income depends critically on these policy variables. If the federal government controls the Bank and gas prices are deregulated, the most likely alternative, the increase in regional income, is one tenth what it would be if the region took all the lease and royalty payments. And the increase in real income of the people who would be adversely affected by the environmental impact of the oil is perhaps one hundredth or one thousandth of the region's share.

Thus, it becomes quite rational for those in the immediate vicinity of a development to oppose it, for they see only a minute proportion of the economic benefit of this particular development and all the environmental disbenefit. This problem becomes a social tragedy if, and only if, it would have been possible to compensate those whose environmental well-being is decreased by using some of the economic benefits from the development. Assume, for example, that one million people were affected adversely by a development which would increase national income by 1 billion dollars, or 5 dollars per person. However, the people who were adversely affected feel they would have been better off with an increase in consumption power of 100 dollars and the development, although they consider themselves worse off relative to the status quo. In this case, if a means could be found by which the nation as a whole could transfer 10 percent of the economic benefit to those adversely affected environmentally, then everyone would be better off by his own value system with the development than without it. Failure to take advantage of situations where it is possible to make everyone better off by his own value system is my definition of social tragedy. Social stupidity is perhaps a better word.

Of course, a perfect compensation scheme like this hypothetical one is politically not feasible. But this does not mean that an imperfect compensation scheme, one which approximates the hypothetical scheme, could not be worked out. We certainly haven't tried very hard to find one. Instead, most of our recent legislation seems aimed at identifying and indefinitely delaying any development which is going to affect someone adversely. If we followed this line of reasoning to its logical conclusion, of course, we would never do anything. We are consequently presently enmeshed in making a series of inconsistent and uncomfortable compromises and, so far as I can see, the only beneficiary of this process is the paperwork industry which has sprung up to write, interpret, and rebut environmental impact statements.[2]

Surely, even rather straightforward, broad-based compensation schemes would be an improvement. One obvious idea, for example, is for the adjoining coastal state to receive, say, 50 percent of the lease and royalty payments; these payments would serve to localize a sizable portion of the economic benefits in the general area that would be disturbed. My guess is that with a little ingenuity we could construct a reasonably effective compensation system. If we had such a system and we found that in a particular case we could not compensate those adversely affected by a development out of the project's economic benefits, then we could be reasonably confident that the net effect of the development on society's welfare is negative and it should not take place. On the other hand, those projects for which such compensation was possible would be undertaken almost as a matter of course.

If, as its proponents claim, offshore oil falls easily into the category of developments we should undertake, then it should be relatively easy to develop a satisfactory compensation scheme. The burden of proof seems to me to be on the proponents.

One final thought: in this discussion, I have assumed that even extensive exploitation of domestic offshore petroleum would have little effect on the OPEC selling price. Under the present scheme, I believe this would be true. Given the difference between the cost of imported crude and the cost of offshore oil, each discovery would be developed quickly and its individual output swallowed up by the massive U.S. consumption without noticeable effect on the worldwide situation. Certainly, the North Sea appears to have had little effect on OPEC prices.

However, if the United States and the other market nations were to follow a strong, coherent policy of developing an importer's bargaining position, then offshore oil could be an important item in such a program. Such a policy would involve getting ourselves into a position where a buyers' boycott of a year or so is a credible threat. It would include importing more than our consumption and storing it, overdeveloping present fields and underproducing them, and exploring and developing extensively new fields, principally offshore, and not producing these fields. As the industry has pointed out, a policy like this would be extremely expensive. But it is still worth considering seriously. If, in the future, the threat of a boycott like this were to keep the OPEC price one dollar per barrel less than it would otherwise be, it would be worth spending in excess of 40 billion dollars now to achieve the capability for such a threat. The National Petroleum Council (NPC) estimated a year's worth of storage would cost $6 to $10 billion.

I am not arguing here for this kind of policy. I only point out that if the United States were to follow a policy like this, then its handling of offshore oil would have to change from present practice. Obviously, one cannot expect private capital to fund extensive exploration and overdevelopment of production facilities, and then shut in the entire process just to use it as a bargaining chip to bring oil prices down. If we were to use offshore oil as a bargaining chip, we would have to make that decision now and begin to make the necessary adjustments in our offshore petroleum management policy.

[1] Currently, under a contract from the Council on Environmental Quality, we are repeating these analyses for a dozen potential development sites on the Atlantic shelf as far south as northern Florida and for a half-dozen sites in the Alaskan Gulf.

[2] This is not to imply that we should disregard environmental consequences in allocating resources. My comment is instead aimed at the environmental protection game as it is actually being practiced. A much more efficient set-up would involve heavy dependence on effluent charges, which would force developers to consider environmental impacts of their proposed developments as a matter of course.

INNOVATIONS IN HEAT DISPOSAL IN THE OCEANS

Dr. Donald R. F. Harleman

Heat is the ultimate waste or by-product that results from all energy production and conversions associated with man's technological development. Heat is unique as a waste product because it is not subject to "treatment" in the usual sense, since the earth's atmosphere is the only readily available heat sink and any attempt at treatment leads to the production of additional waste heat. On a global basis, the projected growth in thermal waste to the year 2000 is not expected to significantly affect the earth's climate. However, "heat islands" created by metropolitan areas have regional climatic effects.

The largest concentrated sources of waste heat are those associated with generating electric power by fossil or nuclear fuels. In the latter case, for every kilowatt of electrical power generated, the equivalent of two kilowatts of power must be dissipated to the environment as waste heat. The economics of scale dictate power producing units of approximately 1000 MS (electrical) and single sites containing 500 MW of capacity are in the planning stage.

Waste heat is continuously removed by circulation of water in the steam condenser cycle. In an open or "once-through" cooling system, new water from an adjacent water body is pumped through the generating station and discharged at an elevated temperature back into the waterway. The added heat is ultimately transferred to the atmosphere by surface heat exchange. In a closed-cycle system, the condenser cooling water is recirculated; and provision must be made for heat removal before the water is returned to the plant. This may be accomplished by a cooling pond (an enclosed body of water in which the surface temperature builds up until all of the waste heat is transferred to the atmosphere by surface heat exchange) or by cooling towers.

All forms of heat disposal have local environmental effects. In once-through systems these may be caused by entrainment of organisms at the condenser water intake and by the effect of increased temperatures in the receiving body of water. In closed-cycle systems environmental effects may be caused by fog or salt deposition produced by evaporating large quantities of fresh water or sea water in the circulating system. Cooling ponds require large land areas. Forced-draft, evaporative cooling towers may result in local noise pollution from the large motor driven fans. Natural draft towers 400 to 500 feet high may be aesthetically undesirable.

The trade-offs in the environmental effects of power plant siting and among the various techniques of waste heat disposal become most acute in the coastal zone where population densities are high and where shoreline areas are in demand for recreational uses. It is important, therefore, to assess the heat assimilative capacity of our coastal and ocean waters and to devise ways of discharging waste heat that will have a minimal impact on the marine ecology. Several examples, drawn from recent research in M.I.T.'s R.M. Parsons Laboratory, will be used to illustrate this minimal impact concept.

ONSHORE COASTAL SITES

A well-designed submerged, multiport diffuser is an effective device for dispersing large quantities of waste heat in coastal waters. The objective is to provide a rapid dilution of the higher temperature cooling water by entrainment with the receiving water within a limited mixing zone. Since cooling water flow rates are large it is usually difficult to achieve sufficient dilution from a single submerged jet. Thus, a series of jets spaced at intervals along a common discharge pipe can be employed to increase the dilution and to reduce the maximum temperature rise above the ambient level.

A large number of factors enter into the design of an optimal diffuser. Among these are the depth of the receiving water and the magnitude and directions of prevailing currents. In coastal waters, prevailing currents result from a combination of wind and tidal effects. If, as is often the case, tidal effects dominate, the current direction will reverse during each tidal cycle. The important variable from the standpoint of the diffuser is the length of the multiport array. For a given power plant site, this determines the rate of heat input per unit length and the maximum temperature rise within the mixing zone is a direct function of the diffuser length. A number of recent thermal-hydraulic model studies of multiport diffusers for specific coastal sites have been made.[2,3,4] These studies, with basic investigations on simplified geometries which are not site-specific, have resulted in general information for the design of multiport diffusers.[5] Some examples are shown in the following figures.

Fig. 1 shows water surface isotherms (temperature rise above ambient) measured in a laboratory basin for a multiport diffuser discharging into a quiescent body of water. The axis of the diffuser is along the line $x/H = 0$, and extends from $y/H = 0$ to $y/H = 10$, where H is the mean water depth. The diffuser nozzles discharge in alternating directions perpendicular to the diffuser axis (i.e., in the positive and negative directions parallel to the x/H abscissa). The alternating nozzle arrangement is recommended for coastal waters with reversing tidal currents, but in a unidirectional current system it would be advantageous to orient all jets in the direction of the prevailing current. By symmetry, the horizontal line $y/H = 0$ can be assumed to represent the midpoint of a diffuser of twice the length shown in Fig. 1. The surface isotherms, represented by $\Delta T/\Delta T_o$ (where ΔT_o is the temperature increase through the condenser) show a pronounced concentration of heat toward the midpoint of the diffuser. This is created by the demand for entrainment water which causes a flow of ambient water inward along the axis of the diffuser.

The diffuser shown in Fig. 1 can be improved by directing some of the jet momentum in the y direction as shown by the nozzle orientation in Fig. 2. This counteracts the induced flow along the diffuser axis so that the temperature distribution along the diffuser is much more uniform. If the temperature rise across a condenser is $\Delta T_o = 20°F$, the maximum surface temperatures are approximately 3 F for the diffuser in Fig. 1 and 2 F for the diffuser in Fig. 2. This represents a significant increase in the diffuser induced dilution—from 6.5 to 10—without an increase in the total diffuser length.

Another important difference between the two diffuser designs is in the vertical distribution of temperature shown by the profiles at the right side of each figure. In Fig. 1, the temperature distribution is almost uniform with depth in the vicinity of the diffuser, whereas in Fig. 2, the heated water remains in a stratified layer with essentially no temperature increase near the ocean bottom. This is important for benthic organisms; in addition, because of the stratification, ambient entrainment water can reach the diffuser by inflow along the bottom

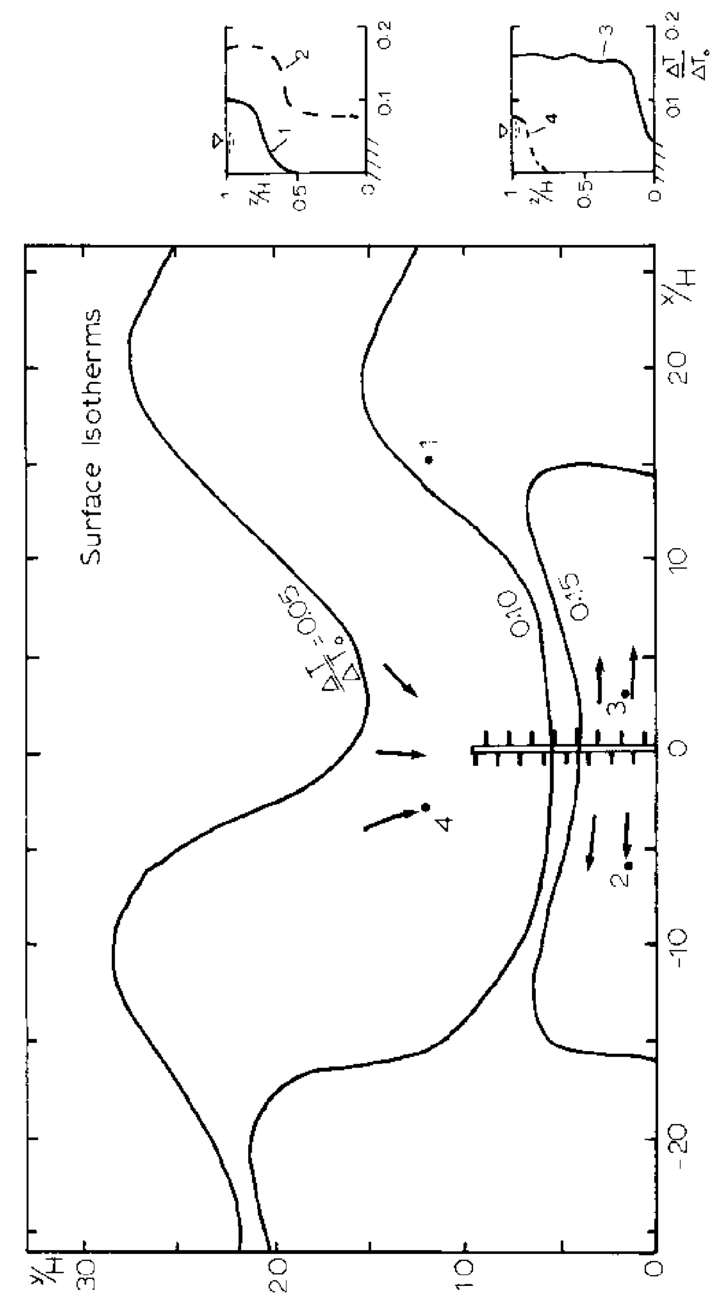

Fig. 1. Multiport diffuser in quiescent water. Nozzles pointing in alternating directions normal to the diffuser axis. Arrows indicate surface currents.

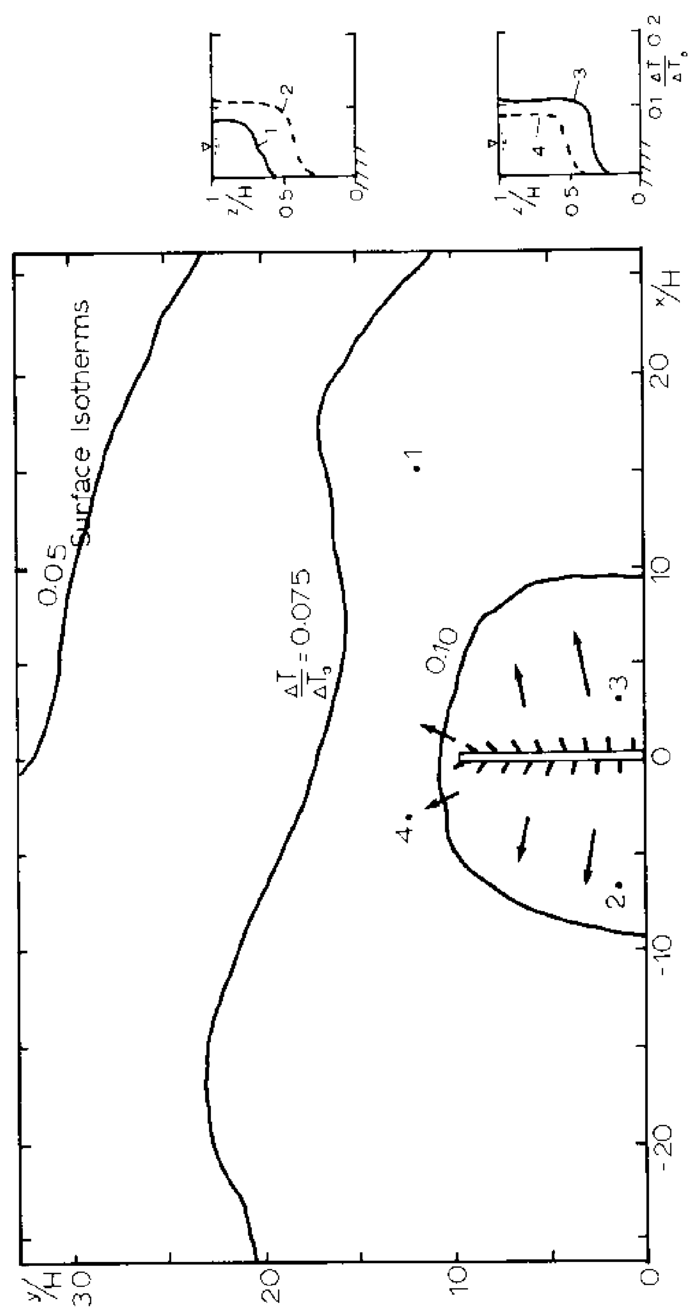

Fig. 2. Multiport diffuser in quiescent water. Nozzle orientation variable along the diffuser axis.

layer. The higher temperatures in the Fig. 1 diffuser are partially due to the reintrainment of heated water near the bottom. Techniques for the design of a stably stratified diffuser are given in footnote 5.

In a tidal system, the stagnant receiving water conditions represented by the diffusers in Figures 1 and 2 are representative of slack tide conditions. If the diffuser axis is oriented with respect to the direction of the prevailing tidal currents, the diffuser performance will improve during nonslack periods. Fig. 3 shows a diffuser correctly oriented, with the axid perpendicular to the direction of the current. In Fig. 4 the diffuser axis is parallel to the current, and it is evident that the area enclosed within the maximum isotherm ($\Delta T / \Delta T_o$ = .075) is considerably larger.

OFFSHORE COASTAL SITES

Limitations on the availability of onshore power plant sites and the advantages of producing floating nuclear power plant units in a shipyard assembly line has led to the concept of the offshore site. One example is the Atlantic Generating Station of Public Service Electric and Gas Company now under design for a site approximately three miles off the New Jersey coast. Thermal discharge and wave motion studies for this station are currently under way in the Parsons Laboratory. Before considering the details of the proposed thermal discharge, it is intersting to consider the heat transport and assimilative capacity of the ocean in the vicinity of such an offshore site.

As a rough approximation, it is assumed that 50 percent of the waste heat input of the power station will be dissipated directly to the atmosphere by surface heat transfer within an area equivalent to a radius of three miles from the plant site. It is further assumed that the remaining 50 percent of the waste heat will be transported away from the plant site by a net coastal current parallel to the shoreline. The average heat input into the ocean from the combined effects of direct solar (short-wave) radiation and atmospheric (long-wave) radiation is approximately 4000 BTU / ft^2-day. Within a circle of the three-mile radius (8 x 10^8 ft^2) the average rate of heat input is therefore about 3 x 10^{12} BTU / day. The offshore station, with an assumed power production of 2000 MW, will produce approximately 3 x 10^{11} BTU / day of waste heat, or about 10 percent of the combined solar and atmospheric input to the three-mile circle. The heat excess above the natural heat content will be transferred to the atmosphere at a rate of about 150 BTU / ft^2 per day for each degree (F) of water surface temperature rise above the natural background temperature.[6] Thus a direct transfer of 50 percent of the waste heat (1.5 x 10^{11} BTU / day) would result in an average water surface temperature increase of

$$\frac{1.5 \times 10^{11} \text{ (BTU / day)}}{150 \text{ (BTU / ft}^2\text{/ day /}^\circ\text{F)} \; 8 \times 10^{8} \text{ (ft}^2\text{)}} = 1.2^\circ F$$

within the circle of a three-mile radius.

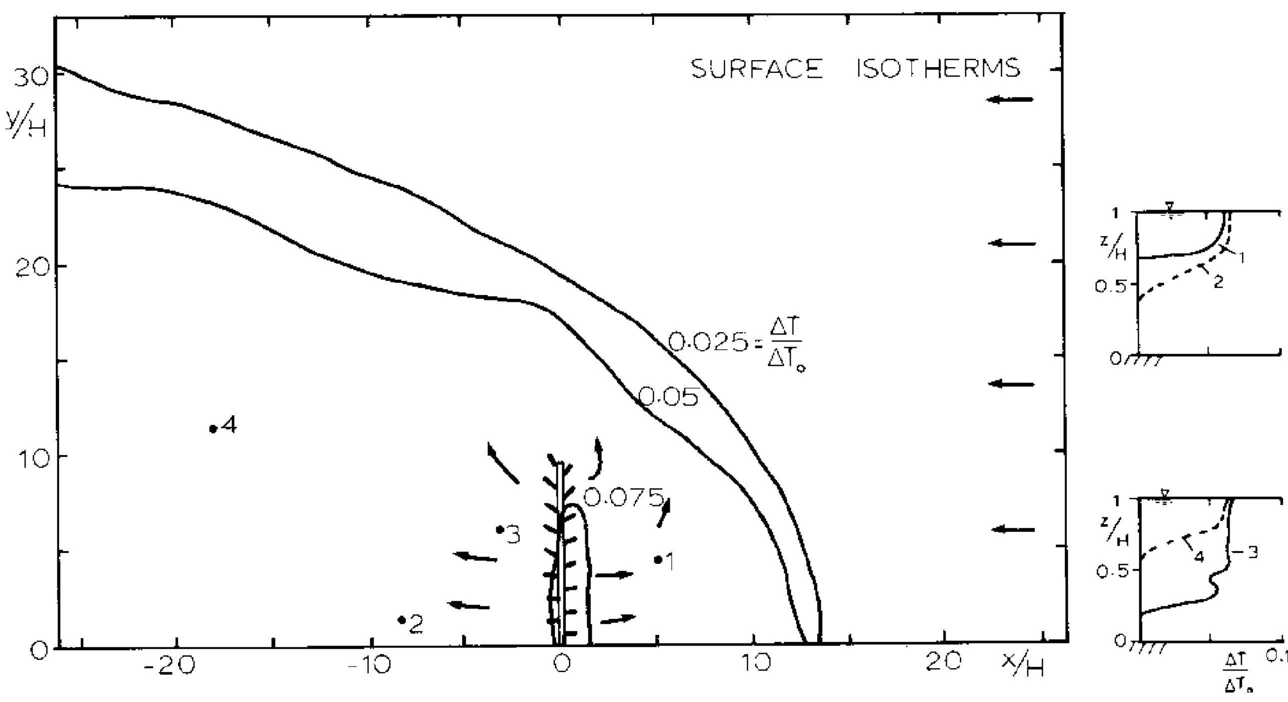

Fig. 3. Multiport diffuser in a tidal current with diffuser axis perpendicular to the current direction.

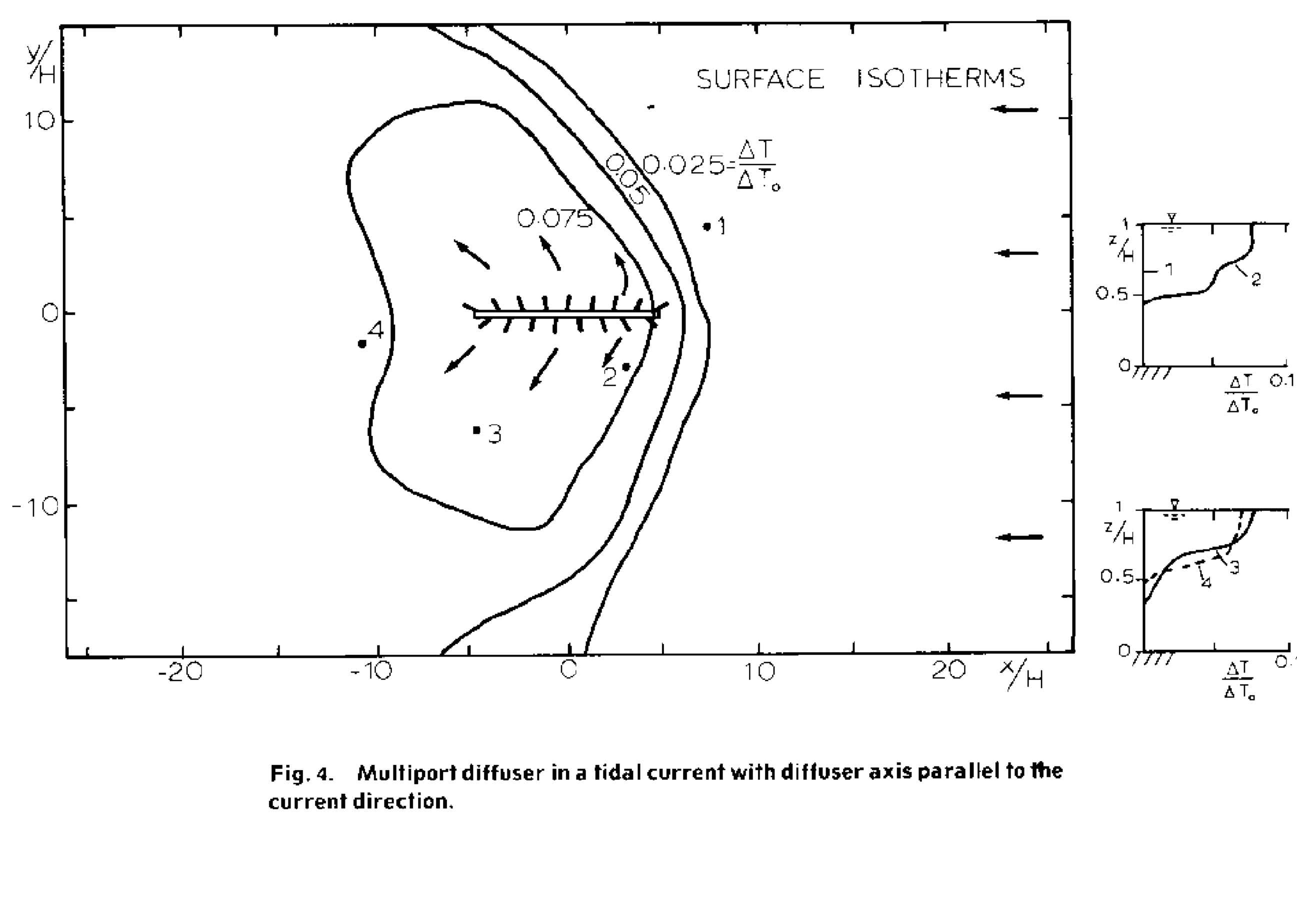

Fig. 4. Multiport diffuser in a tidal current with diffuser axis parallel to the current direction.

The mean water depth in the vicinity of the plant site is 40 feet. It is assumed that all of the waste heat will be contained within a surface layer ten-feet thick. The net coastal drift current is approximately six miles per day, equivalent to a current speed of 0.2 knots. The flow in a six-mile band parallel to the coast is therefore 6×10^{11} lbs. per day. An average temperature rise of

$$\frac{1.5 \times 10 \quad (\text{BTU/day})}{6 \times 10^{11} \ \text{lbs./day}} \approx 0.2 \ \text{F}$$

within the ten-foot layer is sufficient to transport the remaining 50 percent of the waste heat away from the plant.

These calculations provide an estimate of the temperature increase that can be expected in the site area. However, to provide information for an assessment of the environmental impact of the thermal discharge, the design of the discharge structure and the resulting near-field temperature distribution must be investigated.

The breakwater enclosure for the floating nuclear units is semicircular (in plan view), with the straight side essentially parallel to the coastline. The circular portion facing the open ocean is a sloping-mound breakwater, whereas the straight portion on the sheltered side consists of a line of vertical caissons in approximately 40 feet of water. Because of the availability of deeper water on the caisson side and the structural design problem for a discharge structure extending through the sloping-mound breakwater subject to ocean waves, it was decided to locate the condenser water discharge on the caisson side of the enclosure.

There are various relative advantages and disadvantages among possible means of discharging the heated water. A number of alternatives were considered: among them, a near-surface discharge from a series of pipes discharging horizontally from the caisson; a similar arrangement near the bottom of the caisson; or a submerged multiport diffuser. A near-surface discharge usually results in a greater surface area of heated water, but a correspondingly lesser effect on the ocean bottom; conversely, a near-bottom discharge may reduce the surface area of heated water, but it tends to increase the impact of heat on the bottom. A multiport diffuser permits greater dilution and thus greater temperature reduction before the effluent water reaches the surface, but entrained organisms are exposed to elevated temperatures for a longer time because of the greater length of the discharge pipe.

Because of the availability of deeper water adjacent to the caisson, the near-surface discharge appears preferable because it minimizes travel time and bottom temperature and velocity effects. As the horizontal jet exits into the ocean, a sharp interface is observed between the high velocity jet and the ambient water. A turbulent shear is created across this interface inducing an entrainment flow into the jet. The jet flow thus increases and the temperature excess and velocity within the jet decreases. The process continues until the jet velocity is reduced to a velocity comparable with that of the surrounding water. The ratio of the mixed flow Q_s at this stable point to the initial condenser flow, Q_0, is called the dilution.

$$D = \frac{Q_s}{Q_0} \qquad (1)$$

The dilution D is also equal to the ratio of the initial temperature rise ΔT_0 to the average temperature rise in the stable region ΔT_s.

$$D = \frac{\Delta T_0}{\Delta T_s} \qquad (2)$$

Because of the sheared profile of the jet, however, the highest temperatures and velocities usually occur along the centerline of the jet at the water surface and for this reason the stable centerline temperature ΔT_{c_s} is always greater than ΔT_s.

It is generally found that jet entrainment increases with increasing jet momentum (or velocity) and that entrainment decreases with increasing jet buoyancy (or temperature). The densimetric Froude number IF_0 is a measure of the ratio of jet momentum to jet buoyancy. A three-dimensional mathematical model for determining temperature, velocity and flow rates at various distances from a buoyant surface discharge in unconfined and unstratified waters has been developed.[7,8] The following relations apply in the stable region of the jet.

$$D = \frac{\Delta T_0}{\Delta T_s} \approx 1.4 \ IF_0' = 1.4 \ IF_0 \ A^{1/4} \qquad (3)$$

$$\frac{\Delta T_0}{\Delta T_{c_s}} \approx IF_0' \qquad (4)$$

and

$$\frac{h_{max}}{\sqrt{h_0 b_0}} \approx .42 \ IF_0' \qquad (5)$$

where IF_0 = densimetric Froude number $= u_0/\sqrt{g' h_0}$;

A = discharge channel aspect ratio h_0/b_0 ;

$\mathrm{IF}_0' = u_0/\sqrt{g'(h_0 b_0)^{1/2}}$;

u_0 = discharge velocity $= Q_0/2h_0 b_0$;

g' = reduced acceleration of gravity at point of discharge $= \dfrac{\Delta\rho_0}{\rho_0} g$;

h_0 = discharge channel height;

b_0 = discharge channel half-width; and

h_{max} = maximum vertical penetration of the jet.

IF_0' is a controlling parameter and can be rewritten as

$$\mathrm{IF}_0' = \frac{2^{1/4} u_0^{5/4}}{g' \; Q_0^{1/4}} \qquad (6)$$

If Equations (5) and (6) are combined,

$$h_{max} = \frac{.35 Q_0 u_0^{3/4}}{g'^{1/2}} \qquad (7)$$

For a given discharge flow and condenser temperature rise (Q_0 and g' are specified), stable dilution and centerline temperature rise are directly proportional to IF_0' and hence to $u_0^{5/4}$; and the maximum vertical penetration of the jet is proportional to $u_0^{3/4}$. The above analysis is valid for unconfined jets in which the vertical development of the jet is not hindered by the ocean bottom.

An example of the analytical prediction of a temperature field for a surface jet with IF_0 = 4.4 and A = 0.35 is shown in Fig. 5. Using the equations above, it is possible to design a surface discharge without bottom interaction by setting h_{max} equal to the water depth at the point of discharge. However, it may be desirable to increase the near-field dilution by allowing a small zone of bottom interaction. At

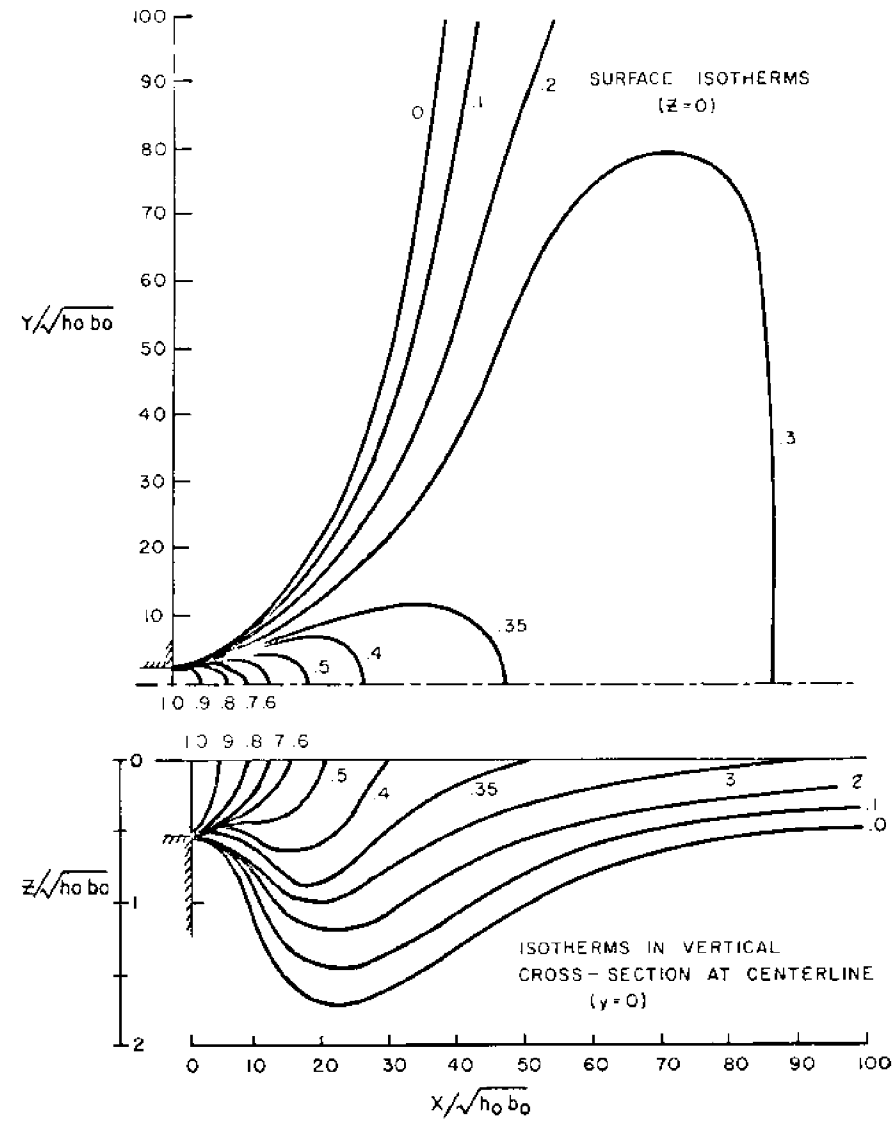

Fig. 5. Isotherms for a heated surface jet, IF_0 = 4.4 and A = 0.35.

the present time, an analytical prediction of this condition is not possible, and it is necessary to resort to experimental information from hydraulic model tests.

An example of a near-field temperature distribution obtained from a model test for a condenser discharge and temperature rise typical of the Atlantic Generating Station is shown in Fig. 6. The condition shown is that which would prevail under slack current conditions. Currents in the along-shore direction, parallel to the caissons, will deflect the jet in the direction of the current. This condition, shown schematically in Fig. 7, also depicts the transition from near-field to far-field conditions.

In the near-field region the temperature distribution is characterized by the physical mixing processes induced by the discharge, and it depends to a large extent on the induced flow itself. Further from this region, in the "far field," the velocity of the effluent flow is near the magnitude of ambient currents, and mixing occurs at a slower rate. Temperature reduction in the far-field is caused by surface heat transfer, convection and ambient turbulent diffusion. The temperature distribution is thus determined near the outlet by jetlike diffusion and in the outer region by natural processes. The prediction of temperature distributions is very complex, but a basic understanding of the processes has been achieved: turbulent jet theory and solutions to convective diffusion equations are well established and predictions of surface heat loss rates are now possible. The final analysis will depend on careful field observations of ambient current directions and magnitudes and on turbulent diffusion coefficients obtained from dye discharge tests at the site.

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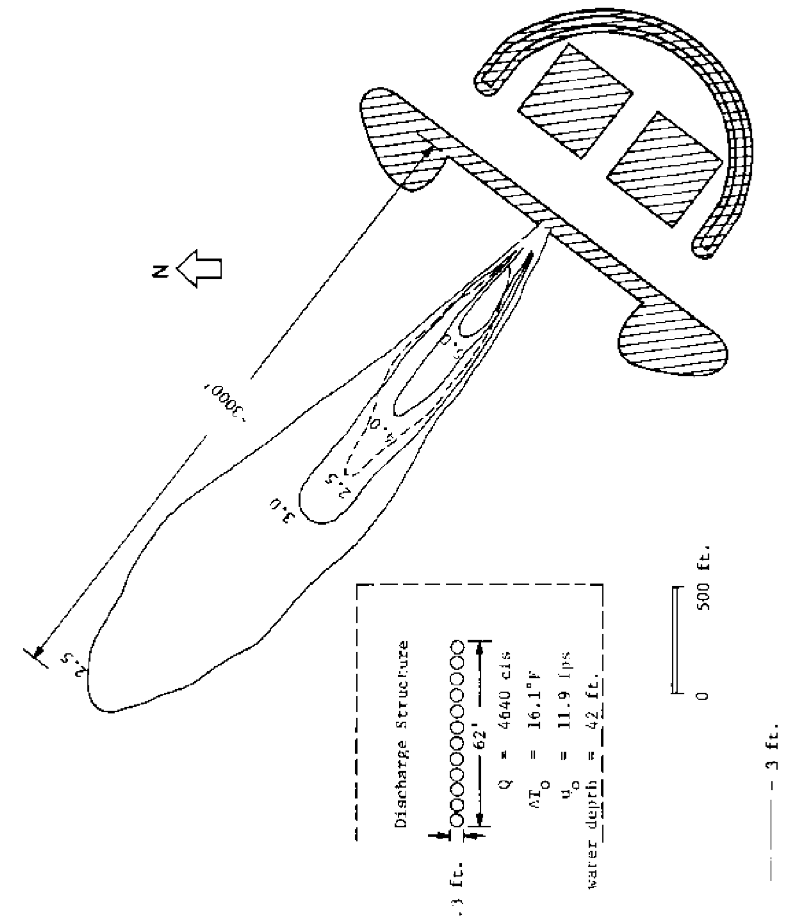

Fig. 6. Typical isothermal rise (°F).

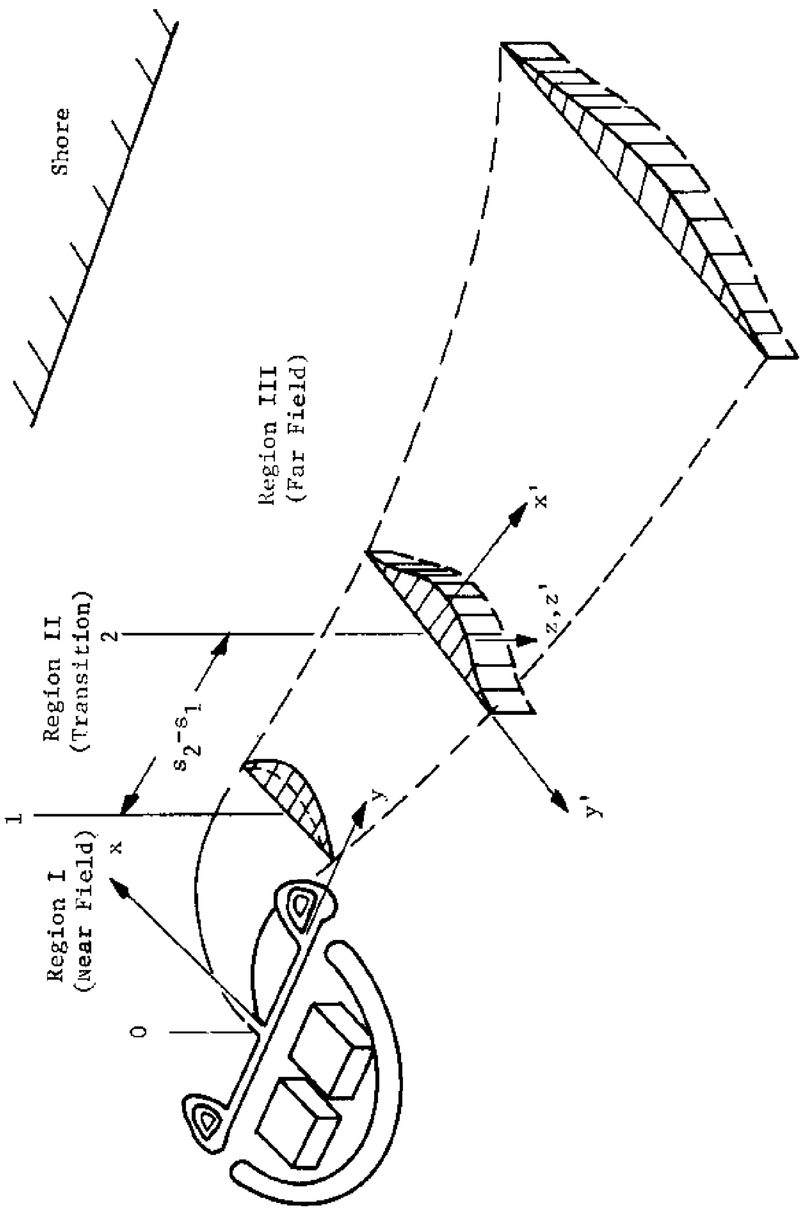

Fig. 7. Regions of analysis.

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BIOGRAPHIES OF SPEAKERS

DR. WILLIAM EARL SHOUPP

World energy and the oceans are both controversial and timely subjects which concern all nations and people of the world. Dr. Shoupp is Senior Vice President of the Westinghouse Electric Corporation, Research, under whose direction much progress has been made in the fields of nuclear engineering, oceanography and environmental protection,

Dr. Shoup holds the distinguished positions of Chairman of the Marine Board of the National Academy of Engineering and President of the Marine Technology Society.

He has served the Westinghouse Electric Corporation since 1938 shortly after receiving his Ph.D. in physics from the University of Illinois. His positions include Manager of Electronics and Nuclear Physics Department (1943-1945); Director of Research, Director of Development and Assistant Manager-Development, Bettis Atomic Power Laboratory (1948-1954); Technical Director, Atomic Power Division (1954-61). Dr. Shoupp served as Vice President, Research, Research Laboratories from 1962 to 1973.

Dr. Shoupp has authored over sixty formal publications in reactor engineering, nuclear physics, electronics and research management, and numerous corporation technical reports covering work on electronics, nuclear physics and atomic power.

He holds patents in electronics, applications of nuclear radiation, nuclear reactors and in material processing.

Among the many awards which Dr. Shoupp has received are the Industrial Research Institute Medal for 1973, Honorary Sc.D.s from both the Indiana Institute of Technology (1972) and Miami University (1956), and the Alumni Honor Award of Distinguished Service in Engineering (1967) from the University of Illinois. He is a member of Phi Beta Kappa.

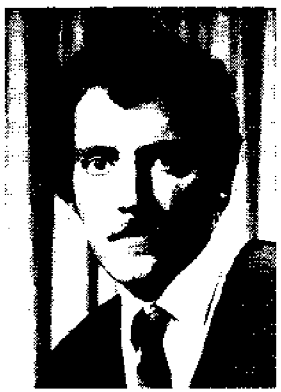
In his long distinguished career, Dr. Shoupp has served as President of the American Nuclear Society (1964) and Chairman of the Nuclear Standards Board of the U.S.A. Standards Institute. He is a Fellow in the American Society of Mechanical Engineers, the American Physical Society, the Institute of Electrical and Electronic Engineers and a Member of the Industrial Research Institute, Inc.

Presently, Dr. Shoupp is a Member of the Visiting Committee to M.I.T.'s Department of Ocean Engineering and formerly served on the Visiting Committee to the Department of Nuclear Engineering at the Institute. He further holds membership on the Commission on Natural Resources of the National Research Council.

In his present position, Dr. Shoupp is responsible for basic, applied, and developmental research conducted at the Research Laboratories of the Westinghouse Electric Corporation in support of the Company's sixty-four manufacturing plants and for various Federal agencies. He directs the scientific and engineering activities of over 700 professional employees, many of whom are world-renowned authorities in their fields.

As Director of one of the first industrial research laboratories in the world, Dr. Shoupp is charged with guiding investigations in disciplines as varied as molecular electronics, magneto-hydrodynamics, cryogenics, life sciences, laser research, mechanics, and in scores of other scientific and technological areas.

DR. JOHN W. DEVANNEY III



A faculty member at M.I.T., Dr. Devanney has received nationwide recognition for his research on offshore petroleum development. Dr. Devanney is presently associate professor of Marine Systems, in the Institute's Department of Ocean Engineering.

Dr. Devanney served as project leader for the Georges Bank Petroleum Study, a major MIT Sea Grant effort in which the potential economic and environmental impact of petroleum exploration and development was studied. The research is recorded in the three-volume work of the same title published in February 1973.

Dr. Devanney has been associated with several other M.I.T. Sea Grant projects. The publications which resulted from these projects are:

"Economic Factors in the Development of a Coastal Zone " (with E. Derbis, Professor W. W. Seifert, and W. Wood) 1971.

"Economic Aspects of Solid Waste Disposal at Sea " (with V. Livanos and J. Patell) 1971.

"The Economics of Fish Protein Concentrate " (with G. Mahnken) 1971.

"The Economics of Arctic Oil Transportation " (with Assistant Professor J. B. Lassiter III) 1971.

"Marine Decisions Under Uncertainty," 1972.

His current Institute work includes the Atlantic/Alaskan Outer-Continental Shelf Study for the Council on Environmental Quality and also research and supervision of coastal zone and land use projects.

Professor Devanney has also served as Senior Scientist for Advanced Marine Technology Division of the Litton Industries (1968-69), Research Associate in M.I.T.'s Department of Naval Architecture (1967-68) and Research Assistant in the Department of Civil Engineering (1965-67) also at the Institute. Previously, he was Operations Analyst for the Electric Boat Division of General Dynamics (1963-64).

Dr. Devanney received his Sc.D. in Operations Research from M.I.T. in 1967. Among his recent publications are "Fundamentals of Port Pricing and Expansion," (with T. G. Hok and G. K. Loon) in 1972 and "Conference Rate-making and the West Coast of South America," (with V. Livanos and R. Stewart) also in the same year.

DR. DONALD R. F. HARLEMAN

Disposal of heat in the oceans is a relatively recent topic of concern in ocean engineering. Dr. Harleman has focused his exceptional expertise on fluid transport and mixing processes.

Dr. Harleman is professor of civil engineering and head of Water Resources Division and director of the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics of the Department of Civil Engineering at the Institute. He received a Sc.D. in civil engineering from M.I.T. in 1950.

His major research interests include fluid transport and mixing processes as they affect the fate of effluents discharged into lakes, rivers, reservoirs, estuaries or the oceans. He has constructed mathematical and physical models for water quality control. Dr. Harleman also has contributed significantly to coastal engineering and tidal hydraulics, stratified flow due to temperature and salinity, waste heat disposal associated with electrical energy generation by fossil or nuclear fuels.

Among the many distinctive positions in which he has served, Professor Harleman has held the position of Visiting Professor at the California Institute of Technology. He has also served as Senior Visitor in the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge.

Professor Harleman has won numerous prizes and awards including a Guggenheim Fellowship, University of Cambridge (1968-69), the Karl Hilgard Prize of the American Society of Civil Engineers (1971) and the J. C. Stevens Award also of the American Society of Civil Engineers.

He is also a Member of the Board of Editors of the Journal of Hydraulic Research and Member of the Committee on Fundamentals of the International Association for Hydraulic Research.

Dr. Harleman is affiliated with the American Geophysical Union, the Water Pollution Control Federation, the International Association on Water Pollution Research, the American Society of Limnology and Oceanography, the Boston Society of Civil Engineers and the Committee on Power Plant Siting of the National Academy of Engineering.

He is a member of the Task Force on Technical Aspects of the Technical Advisory Committee on Conservation of Energy of the Federal Power Commission.

Among his voluminous contributions to the literature in his field which are too numerous to discuss here, is volume 4 (1972) of the Annual Review of Fluid Mechanics entitled "Fluid Mechanics of Heat Disposal from Power Generation" (with K. D. Stolzenbach).

Professor Harleman previously published the Sea Grant technical reports:

"A Mathematical Model for the Prediction of Unsteady Salinity Intrusion in Estuaries" (with M. L. Thatcher) 1972.

"Numerical Model for the Prediction of Transient Water Quality in Estuary Networks" (with J. E. Dailey) 1972.

"Characteristics of Condenser Water Discharge on the Sea Surface (Correlation of Field Observations with Theory)" (with S. C. Doret, A. T. Ippen, and B. R. Pearce) 1972.