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NUCLEAR ENERGY AND ELECTRICAL GENERATION

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NUCLEAR ENERGY AND ELECTRICAL GENERATION

Your Program Chairman asked for a discussion of some of the fundamental aspects of nuclear energy as they are related to electrical power generation. The program brochure for this particular talk indicated that today I am to describe how the atom generates electricity, the fission process, the kinds of power reactors that are being constructed, and what unique features are defined in these power reactors by some of the fundamental laws of nature. At first glance I didn't know whether I should prepare an advanced physical chemical lecture or a short course in applied nuclear engineering. However, in contrast to a comprehensive understanding of nuclear technology, it occurred to me that what you probably desire is a better understanding of some of the impassioned dialogue, conflicting claims, and countercharges that are now heard in the public forums about reactors. You hear statements about the energy crisis, the perils of the peaceful atom, radiation and thermal ecological damage, and other popular clichés. With our mass communication system and the growing number of professional, pseudo-scientific antagonists, such as Nader and others, you are exposed to an obvious controversy which involves scientific jargon and principles that are not universally understood.

With the limited time available today, it will not be possible to start from first principles and develop a detailed, comprehensive description of the nuclear process and nuclear reactors. Instead, what I plan to do is to provide some background and insight into three aspects of the nuclear power controversy that are currently in the vogue. The first of these is the energy crisis. Is nuclear energy necessary or even desirable in the total scheme of energy needs that we foresee at this time? The second aspect of nuclear power which can evoke spirited dialogue is the radioactivity releases from reactors. Is radiation a necessary part of nuclear power generation, and is it a hazard? The third aspect of nuclear power plants, which is a popular topic, is that of thermal pollution. Is it necessary to release heat from power generation facilities, and are the waste heat discharges a real detriment to the environment? Within the framework of these three contemporary issues, I will first identify in general and hopefully understandable terms the fundamental laws of nature that apply to these issues. Second, I will attempt to show how these constraints, the constraints imposed by nature, affect the characteristics of nuclear and fossile power facilities. And finally, I won't be able to resist the opportunity to indicate how the scientific community views these issues.

The energy crisis - is it a real or imagined need for additional power to support and extent our way of life? There are various sources and forms of energy in use today. Examples include the internal combustion engine, fossile fuels for heating and cooling of our homes, solar energy is used for electrical power for spacecraft, and chemical energy is used to make explosives, to refine metals, and other detrimental or beneficial uses. In these examples energy is used for either doing work or providing heat. In fact, the thermodynamicist defines energy as the property of a system which can be converted into either heat or work. If we look at electrical power needs for the future, and recall that electrical power is only one form of energy consumption, we project that as much power will be used in the decade of the 70's as has been used in the previous nine decades.

Furthermore, the electrical generating capacity in the United States must triple to just keep pace with the projected demands between now and 1990. These increased demands result in part from an increased population, but more significantly it results from increased energy consumption by each member of our society. It's not the electrical toothbrush by itself which is responsible, it's not the widespread use of aluminum which requires electricity for its refining, and it's not the fact that more and more homes are either heated and/or cooled by electricity which has created the problem, but collectively and in total, the electrical energy uses now equal the generating capability which is available. In the near future electrical use could quickly out distance generation without some conserted effort to keep pace or reduce projected demands.

There are currently three sources of energy which are being used to generate electrical power. Hydroelectric dams are the most familiar to us in the Pacific Northwest. The energy source in this instance is <u>solar energy</u> and the conversion process is familiar to each of us. The sun's energy evaporates the oceans, the clouds deposit rain at the high elevations, and dams are provided to turn the hydroelectric generators as the water is returned back to the oceans. At this time most of the good sites for dams have been used, and there are some undesirable environmental concerns associated with additional dams. Consequently, hydroelectric power cannot be thought of as the way to solve future energy deficits.

A second source of energy for power generation is the chemical energy available in our fossile fuel natural resources. Carbon and hydrogen in the form of coal and natural gas are converted into another chemical form by burning, and the heat which is released is used to make steam which turns large turbine-driven generators to produce the electricity. There are three reasons why fossile fuel chemical energy is not a fully satisfactory answer to all future power needs. These are as follows. First, these natural resources are only available on limited quantity, and in the case of oil and natural gas, reserves are rapidly being exhausted. Coal reserves are projected to last for some time into the future, however, the desirability of the coals which will have to be consumed is substantially reduced due to contamination by undesirable chemical elements. Which introduces the second undesirable aspect of fossile fuel plants, namely that they are a major source of environmental pollution particularly with respect to sulphur and nitrogen containing compounds. The third and perhaps least desirable aspect of fossile fuel usage is that these resources are too valuable for other uses. The petro-chemical industry makes a substantial contribution to our economy based on conversion of these natural resources into fabrics, construction materials, food stuffs, and other valuable commodities.

The third and newest energy source for electrical power production is nuclear energy. The electrical power conversion is identical to that when fossile fuels are used, the difference being that nuclear fuel is used in place of fossile fuels to provide the source of heat. I am sure that all of you have seen the famous letters $E = MC^2$. It seems as though every cartoon which involves an atomic energy or scientific setting has these letters written on a blackboard. This expression was developed by Einstein in the 1930's, and is the fundamental principle which underlies nuclear energy. It merely asserts that matter (M) and energy (E) are really the same property, and that they are related by a universal constant (C) which just happens to be the speed of light. In other words, if a small mass (or weight) of any material, say 0.001 pound is totally converted to energy, Einstein's formula permits us to calculate that about 40 billion BTU's or British Thermal Units of energy would be produced. Since BTU's may be foreign to some of you, let's relate that to the amount of coal which would need to be burned to produce the same amount of energy. About 3.0 million pounds of coal would be required to produce by chemical processes the amount of energy that would be available from .001 pound of mass completed converted to energy.

A nuclear reactor is nothing more than a device to accomplish this mass to energy conversion. Uranium and a few other heavy atoms have the property that when they are bombarded by subatomic particles called neutrons, the atoms fission. Now fission is nothing more than a scientific cliché for the sequence of events where a heavy atom is disintegrated into two or more lighter atoms, some extra neutrons, and some energy corresponding to the amount of mass which is destroyed. If we conduct an experiment where we weigh a given amount of uranium, put it into a reactor to undergo fission and weigh the lighter atoms or fission products which are produced, we will find that a certain amount of weight will be missing. If we also measure the amount of energy which is released during this experiment, we find that it is exactly what would be calculated by Einstein's $E = MC^2$ formula for the missing weight. Simply stated, Einstein's relationship and the fission process are the fundamental characteristics of nuclear energy.

Compared to other forms of energy, this energy source has some distinct advantages and some disadvantages. Reactors can be built nearly anywhere with a resultant electrical cost which can be competitive with that from building new dams. The energy is more concentrated so that it's not necessary to transport and process large quantities of fuel. Substantial uranium reserves have already been identified for immediate use, but even more important a reactor concept known as the breeder reactor is being developed to assure the availability of fuel for many, many years. In this breeder reactor a material such as thoria, which is not capable of undergoing fission, is converted to uranium which then can be used as a fuel for a nuclear power station. At the same time heat is generated to produce electrical power. So we not only obtain the electrical power but we also get the fuel for another reactor - a situation which is very difficult to improve upon.

Nuclear energy has a particularly desirable feature compared to fossile fuel in that it does not release pollutants that are foreign to the atmosphere. Burning of pure fossile fuels produces only carbon dioxide and water. Both of these chemicals are found in great abundance in our atmosphere. In fact, CO_2 is an essential ingredient in the photosynthesis reaction in which CO_2 is converted into chlorophyl, cellulose, and other plant structures, and of course oxygen is released. Unfortunately, all fossile fuels are contaminated with sulphur and nitrogen compounds, and oxides of these materials do not occur naturally in the atmosphere in any significant quantity. In the body they can combine with water to form damaging acids, particularly in the lungs. They are also the pollutants which can cause extensive other damage to humans, vegetation, as well as man's structures.

There is a form of environmental release which is unique to nuclear energy, and this brings us to the second popular topic in the vogue today - the release of radioactivity. You recall that when a heavy atom is fissioned two or more of the lighter atoms are produced. As a general rule, these fission product atoms are initially unstable, and in the process of becoming more stable they emit radiation. Although every precaution is taken to keep these radioactive substances bottled up within the uranium fuel assembly in the nuclear reactor, inevitably a small amount of radioactive material is released. There are very strict regulations which are rigidly enforced by the AEC to assure that radioactive discharges are kept at the lowest possible levels and, as a minimum, below Federal Radiation Council guidelines. The limits on concentrations of radioactivity permitted in power reactor liquid effluents leaving the plant area prior to dilution in a body of water are sufficiently low that a member of the public could drink this water throughout his lifetime without exceeding the radiation guide levels. Concentrations in the effluents, of course, are even further reduced by dilution in a body of water into which they are discharged.

There are those who believe that present limits on releases are too liberal when viewed in comparison with the even lower levels that reactors are capable of achieving as shown by operating experience. This gives rise to the criteria that currently exists within radiation protection circles and that is that exposures to the public should at all times be kept as low as practicable. The point at which as low as practicable has been achieved is always a matter of degree and involves some arbitrary judgement. Although the "lowest practicable" criteria works well when discharges are large and straightforward techniques are available to make substantial reductions at minimum cost, when further reduction in discharges require larger sums of money some controversy is bound to develop regarding what is and what is not preacticable.

I personally approach this issue of discharge of radioactivity by examining the radiation exposure from power reactors in terms of radiation exposure resulting from natural causes. We are constantly exposed to radiation from many sources in our normal way of life; cosmic radiation from outer space, naturally occurring radiation from rocks and building materials, radioactive atoms in the foods and liquids that we consume. This radiation is referred to as background radiation, and it varies depending on the geographic location. Without elaboration of what the term means, the basic unit of radiation dose is called the mR. Natural background radiation dose varies from 70 to 250 mR per year within the United States. In Denver, Colorado and other high altitude locations doses will be closer to the 250 mR; at sea level, particularly in the Southeastern part of the United States, doses are closer to 70 to 100 mR per year. There are locations in the world where background doses are more than 1600 mR per year, such as in certain habited areas near volcanic locations in Brazil. In our affluent society we have introduced new ways to provide additional radiation exposure. For example, a round trip cross-country flight from Portland to Washington, D.C. and return at an altitude of 35,000 feet provides a dose of 3 to 5 mR due to cosmic radiation. A chest X-ray results in a dose in the 20 to 500 mR range, and other medical procedures involve increased exposures.

Within this context, it is now appropriate to inquire about the increased radiation doses which result from the operation of a power reactor. If you live and work at the cyclone fence which defines the site boundary of a reactor complex, your additional radiation dose may be as large as 5 mR per year. If you reside more than a mile away from the reactor, the dose from the reactor-produced radioactivity is less than 1 mR per year. In other words, power reactors cause at most a 5 mR increase in annual radiation dose over the minimum 70 to 250 mR that the people receive from natural radiation which many people increase by plane trips and chest X-rays to substantially higher levels. I conclude that radioactive discharges from power reactors do not represent a hazard to the general public. I don't advocate reducing our vigulance about the detrimental effects of radiation, nor do I recommend that we stop our investigations into radiation effects. I do conclude that when viewing the total risk to the general public from radiation, there are many other more desirable methods of reducing radiation than banning reactors. Currently, about one to two percent of the installed cost of a power station is for systems that minimize the release of radioactivity to the environment. This amounts to about a $2 to $5 million dollar capital investment which is ultimately reflected in increased electrical rates. In my judgement the current release practices are the lowest practicable and do not represent a health hazard.

The final aspect of the electrical power generation which I will only briefly mention today is the subject of thermal discharge. Here we find another fundamental constraint of nature which affects the design of a power facility. It is inevitable that when electrical power is generated, some waste heat must be discharged. The efficiency of power conversion can be altered to vary the amount of waste heat, but some waste heat is a necessary by-product of power production. This a law of Physics that is as inevitable as the law of gravity for example. You are familiar with other examples of this physical law, the radiator on your auto being one. Only about 25 percent of the energy released by burning fossile fuels in the internal combustion engine of your car is used to do the work of moving your car. The remaining 75 percent is discharged to the environment as waste heat. In a nuclear power station about 35 percent of the energy generated from nuclear fission is actually converted to electrical power; the remainder is released as waste heat. Fossile fuel electrical generating facilities operate at somewhat higher temperatures and convert about 40 to 42 percent of the chemical energy released by burning fossile fuels into electrical power. Perhaps because today's nuclear plants dispose of somewhat more heat to the environment than modern fossile fuel plants there is a tendency to associate thermal effects with nuclear plants only. This is a totally erroneous impression since both types of plants are subject to the same constraints of nature and must reject sizable portions of the heat they produce to the environment.

Contrary to many claims, thermal effects are not necessarily detrimental in all situations. The result of thermal discharges may be detrimental, beneficial, or insignificant depending upon many factors such as the matter in which the heated water is returned to the source stream, the amount of source water available , the ecology of the source water, and its desired use. The methods of disposing of heat from electrical power generating plants depends on both economic and environmental factors. The least expensive method is to use once-through cooling in which heated water is returned to an available source. In some situations other methods are used. Artificial ponds can be constructed to provide a source of cooling water for continuous recirculation through the plant. Cooling towers, both the wet and dry variety,are being studied although substantial economic penalties are associated with this method. Actually, there is a good chance that the warm water can be put to good use. This water incidently is bath water temperature and is not a boiling, scalding, caldron of high temperatures. No doubt you have heard of various proposals to use the waste heat water for irrigation to extend the crop growing periods. I am reasonably confident that, as has been the case in other industries where efforts have been made to find desirable uses for by-product streams, the thermal discharges from nuclear facilities will eventually be used constructively.

Today only a few of the fundamental features of nuclear power generation that bear on contemporary issues have been discussed. I have tried to place nuclear power into perspective with other forms of power generation, to identify fundamental differences between methods, and to state some of the advantages and disadvantages of the various power generation techniques. To close, I will state what I believe to be a viewpoint of the majority of the scientific community on the subject of Nuclear Energy and Electrical Power Generation.

We hear much today about the environmental crisis and the danger of polluting the environment to the point where we can no longer exist. We also hear much of an impending energy crisis and the danger of power shortages which could make it impossible for us to live without drastic changes in our standard of living. I believe that nuclear power is the best approach to solving the energy crisis and relieving significantly the environmental crisis. It is essential that we learn to preserve our habitat, our environment, and we must learn how to conserve irreplaceable natural resources, of which fossile fuels are an excellent example. At the same time supplying our needs for electricity will require vast increases in power production to continue and extend our way of life to greater numbers of people. Such power production is possible by tapping an heretofore untapped energy resource and this is nuclear energy. There is a risk-benefit analysis which must be performed. We must characterize the risks, real or imagined from operation or nuclear power stations to the benefits of the power which is produced. As a member of the technical community, I only hope that this decission-making process can proceed logically on technical merits, and that decisions can be reached on the basis of objective straight thinking, rather than emotional bias, overreaction, or panic.