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THE IMPACT OF ENVIRONMENTAL RADIATION AND
DISCHARGE HEAT FROM NUCLEAR POWER PLANTS

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During this time of acute environmental awareness, it is important to recognize that mankind is increasing his use of energy by 3 to 5 per cent per year.

In order to make a quantitative assessment of the environmental impact of power plant emissions, it is necessary to, first, quantify the magnitude of each potential pollutant discharged to the environment. Second, the distribution of these emissions should be calculated initially, and then monitored, to determine the resulting concentrations in the natural environment. The effects of these pollutant concentrations on public health and on the natural ecosystems can then be quantitatively assessed.

Of all the forms of producing and using this energy, electrical power is the most efficient form of energy production and creates the least amount of environmental pollution of any energy source. A detailed examination of environmental factors further reveals that nuclear power provides the most pollution-limiting means for producing electric power.

The two routine emissions from a nuclear power plant are large quantities of discharge heat and extremely small quantities of radioactive isotopes. A general solution of the effects of these small quantities of radioisotopes can be developed and is presented in this paper. A general solution to the effects of discharge heat cannot be developed because these effects are dependent upon the receiving body of water, its quantity, its quality, its biological community and the intended use of the water.

ENVIRONMENTAL RADIATION FROM PWR's

In order to determine the existence or magnitude of public health problems that might result from locating several nuclear power plants in a given area, it is important to determine the average exposure that might result to the general population from the plants. In the past the problem of public exposure to radiation from reactor effluents has been studied for two situations:

1. the case of exposure to the general population following hypothetical accidents and,
2. the case of exposure at the site boundary during normal plant operation.

This paper will cover the additional case of radiation exposure to the general population through normal operation of nuclear plants located on river systems, cooling ponds and sea coasts.

River Plant Site: In previous studies ^(1,2,3) the radiation exposures to the general population from the normal operation of Westinghouse Pressurized Water Reactor (PWR) on river systems were developed in detail. These studies included a quantitative assessment of the radioisotopic emissions used in the design basis. These data were then related to prior experience of operating reactors of this type and to new reactor designs to determine the actual expected emissions from future plants. The results of these studies are summarized here.

Assumptions:

1. A hypothetical 1000 MWe nuclear plant (PWR) was presumed to be located on a freshwater river system as shown in Figure 1.
2. The design basis exposure for normal operations is derived from the assumption that the plant is operating with 1% of the fuel in a failed condition.
3. The actual expected exposure is based on modifying the radioisotopic emissions according to prior operating experience and present fuel cladding design.
4. The calculated exposures included contributions from immersion in a cloud of radioactive gases, intake of radioisotopes contained in terrestrial and aquatic foods associated with this water.

The exposures from these sources are presented in Table 1 where they are compared to the design basis exposure for normal operations maximum exposure and to the recommendations of the Federal Radiation Council and the International Commission on Radiological Protection. These levels of radiation exposure are shown in Figure 2 as a function of distance from the plant boundary as affected by the fraction of fuel elements operating in a failed condition.

Regulation: In the United States, the Federal Radiation Council has the responsibility to recommend the maximum exposure levels for the occupational and non-occupational population. The AEC has the responsibility for regulating and enforcing the emission of radioisotopes from nuclear plants at levels consistent with the FRC recommendations. These two agencies provide consistent guidelines only at the plant boundary where the FRC allows a maximum exposure to any member of the public of 500 mrem/year and the AEC regulations allow, as an upper limit, radioisotopic emissions which would deliver a 500 mrem/year maximum exposure at the site boundary. For the general population away from the site boundary the FRC (and ICRP) recommendations provide for a maximum exposure level of 170 mrem from all manmade radiation sources in addition to natural

**FIGURE 1. TYPICAL REGION FOR
SINGLE REACTOR SITE**

		Site Boundary	Low Pop. Zone 5 miles	General Pop. Zone 20 miles
FRC recommended maximum	Air & Water* Bkgd.	500 <u>130</u> 630	170 <u>130</u> 300	170 <u>130</u> 300
DESIGN BASIS 1% fuel leak	Air & Water* Bkgd.	5.0000 0.2055 <u>130.</u> 135.2055	.1040 .0103 <u>130.</u> 130.1143	.0156 .0093 <u>130.</u> 130.0249
ACTUAL EXPECTED	Air & Water* Bkgd.	0.0063 0.0435 <u>130.</u> 130.0498	0.0001 0.0022 <u>130.</u> 130.0023	0.0000 0.0020 <u>130.</u> 130.0020

*Includes food chain

**TABLE 1. ANNUAL EXPOSURE FROM A
SINGLE 1000MWe PLANT, mrem/year**

**FIGURE 2. ANNUAL EXPOSURE AS A FUNCTION OF
ASSUMED REACTOR FUEL FAILURE AND
DISTANCE FROM SITE BOUNDARY**

background and medical exposures. The emission limits set by the AEC, however, provide a much lower exposure to the public than the FRC recommendations because these radioisotopes are diluted in the environment; the exposure to the general public from maximum AEC emissions is between 1 and 5 mrem/year. A large power reactor would have to operate with all of the fuel in a failed and leaking condition in order to develop the maximum isotope release allowed.

The AEC regulations also provide the requirement that these emissions be held as low as practical. Thus, a normal operating design basis includes the assumption that only 1% of the fuel is operating in a failed condition. Operation at this design level results in an exposure of the general public to from 0.02 to 0.1 mrem/year. From prior operating experience the actual expected exposure to the general public is still much less (0.002 mrem/year).

Radiation from Several Plants on the Same Site: While the resultant radiation exposure to the general population has been examined for multiple plants on the same site, it is obvious that more than 1000 large nuclear plants could be operating on the same site at the level of 1% failed fuel without exceeding the FRC recommended exposure to the nearby general public.

The case of radioisotope build-up in cooling ponds is also important to analyze from a public health standpoint. This analysis considers a 1000 MWe PWR operating in conjunction with a 2000 acre cooling pond having a net flow of one pond volume every two months.

The concentration of radioisotopes as a function of time of operation in this cooling pond is calculated by the formula:

$$C(t) = \frac{R}{V \Lambda} (1 - e^{-\Lambda t})$$

where

R = activity emission rate for the individual isotopes, (Ci/yr)

V = pond volume, (cm^3),

Λ = r/V , (yr^{-1}),

r = rate of water loss from pond, (cm^3/yr),

λ = radioactive decay constant for each radioisotope, (yr^{-1}).

The resulting concentration of radioisotopes in the cooling pond water can be used to compute radiation exposure through drinking water and, with the appropriate food chain concentration factors, through the eating of fish taken from the water.

The exposure which could result to the public would depend on whether this small lake is used for drinking water and/or sport fishing. At the equilibrium concentrations of these radioisotopes in the pond, a person obtaining his average fish diet totally from this small pond would receive an annual exposure of 0.001 mrem; if, in addition, he obtains all of his drinking water from the same source, his environmental exposure would be an additional 0.12 mrems per year.

Radiation Effects at Coastal Sites: For the case of a large PWR power plant located at a coastal site where these low levels of radioactivity are discharged into saline waters, the exposure of the general public would be much lower because these waters are not consumed for drinking. These differences of exposure from fresh and salt water plant locations are shown in Figure 3. The calculated expected exposure drops to 0.0001 mrem/year for the coastal site compared to 0.002 mrem/year for the fresh water plant location.

Compared to natural background levels of 100 to 200 mrem/year and medical exposure of 55 mrem/year these incremental exposures from nuclear power plants are truly insignificant. In any other field of investigation, such exposure levels would be considered as minor perturbations in the noise region and thereby equated to zero.

The role of reactor designers is, however, to continue to improve all aspects of reactor plant and fuel performance, including continued efforts to further reduce all pollution levels. Even lower levels of environmental radiation from nuclear power plants can be achieved with the recently announced (May 1970) "Essentially Zero Release Plant" now being offered by Westinghouse. These further reductions in exposure levels can be achieved at an estimated cost of \$1/KWe in environmental areas where it appears desirable to do so.

FIGURE 3. ANNUAL EXPOSURE AS A FUNCTION OF DISTANCE FROM SITE BOUNDARY

DISCHARGE HEAT IN THE ENVIRONMENT

Most of the energy produced in the world is provided through the process of converting heat energy into mechanical energy. The maximum theoretical efficiency for this conversion process in a "heat engine" is defined by Carnot's law which states:

$$\text{Efficiency (max. theoretical)} = \frac{T_1 - T_2}{T_1}$$

where T_1 and T_2 are the upper and lower temperature limits of the system.

In practice heat engines cannot reach this efficiency limit because friction and other real factors reduce attainable performance. Modern steam turbine equipment provides the highest efficiency of all the heat engines in practical use today. Using high temperature (1000 - 1100°F), high pressure (1800 - 3500 psia) steam, today's modern fossil-fueled steam-electric plants will attain an overall thermal efficiency of 37-38%. However, less than one half of the presently operating fossil-fueled plants attain this thermal efficiency; the average of all fossil-fueled plants operating today being only about 30%.

Nuclear power plants produce steam at lower temperatures (500-600°F) and lower pressure (800-1000 psia) and, thus, have a thermal efficiency of 31 to 33%, which is somewhat below the most modern fossil-fueled plants but somewhat better than the average fossil-fueled plants. The balance of this energy must be discharged to the environment. For example, a 1000 MWe nuclear plant having a condenser flow of about 2000 cubic feet per second will heat the condenser cooling water by 15°F.

In all cases of heat rejection, the ultimate method for cooling is by radiation of this heat to outer space. The heat produced by these various machines will have a somewhat different path on the earth before its final dissipation into outer space. The heat from automotive engines and gas turbines is discharged directly into the atmosphere from which it is ultimately radiated into space. Approximately all of the waste heat from a nuclear plant is discharged through the steam condenser into the cooling water. Fossil plants discharge about 15% of the waste heat into the air

with the flue gas with the remainder being transferred through the condenser to the cooling water.

When condenser discharges are mixed with natural water systems, small temperature rises occur within a limited volume of the water system. The ultimate removal of this excess heat from the water system occurs by three concurrently operating mechanisms:

1. Direct radiation to outer space,
2. Heat transfer to the atmosphere by the evaporation of water, and
3. Heat absorption by the atmosphere through conduction and convection.

Each of these heat release processes are constantly at work in all water bodies, even those lakes and streams found in the pristine wilderness. Adding the discharge heat from power plants simply increases the burden on these natural heat dissipation processes that have been described variously as "thermal pollution", "thermal effect" and "thermal enrichment." It is not possible to judge the extent of thermal discharge effects until detailed investigations are conducted. In fact, the term "thermal effect" is the only one that can be accurately and consistently applied to thermal discharge considerations. Each situation has its own unique features. Equations describing the environmental temperature distribution from discharged heat have been developed by Pritchard⁽⁴⁾, et al, from the consideration of both mixing and surface cooling.

Ecosystem Analysis: In general, the energy flow of an ecosystem⁽⁵⁾ can be characterized by the relationship shown in Figure 4. A stable ecosystem is defined as one in which the photosynthesis productivity and the community respiration are equal. Any system subjected to an alteration or stress will tend to return to the stable state within its capacity to assimilate the change or applied stress. Referring again to Figure 4, increasing the temperature of a stable aquatic system (Point 1) would have the immediate effect of increasing the metabolic rate, and hence, the community respiration (Point 2), but the rate of primary productivity would also be increased to some extent, and eventually a new stable relationship would develop.

FIGURE 4. AQUATIC COMMUNITIES CLASSIFIED ON BASIS OF METABOLISM

The concern with heated discharge revolves around two points:

1. How long will it take for a new stable ecosystem to develop that is adjusted to the applied thermal stress, and
2. What will be the nature of the new ecosystem, i.e., how much change will be incurred in the species and concentration of species of the aquatic community.

For most of the cases where detailed examinations have been made of thermal discharge, there has been no detectable change in the aquatic ecosystem, illustrating that the applied strength is negligible. As more power plants are built and operated using the same water resources, noticeable stress may develop under certain conditions.

For example, the heat discharged from a power plant may interact synergistically with impurities in the water to cause major environmental stress. A river already high in biological oxygen demand from raw sewage, pulp and paper mills and other industrial wastes may develop an oxygen "sag" below the life support level if subjected to the further stress of heated discharges.

While heat is a factor that can increase both community respiration and productivity, its effect may be limited or controlled by other factors such as nutrient levels. Algal blooms, for example, usually require a minimum quantity of phosphate (0.015 ppm) and nitrate (0.20 ppm) nutrients in association with an optimum temperature for population growth depending on the phytoplankton species available. Furthermore, gross increases in temperature can cause a succession in algal species from diatoms to green algae to the undesirable blue-green algae. The temperature requirements for the phytoplankton successions were developed by Cairns⁽⁵⁾ and are presented in Figure 5. A shift in temperature of 8°C (or 14°F) is required to alter optimum production temperature from green to blue-green algae, providing the nutrient levels would also support this bloom. For a nominal 10-foot depth, the area involved is typically less than five acres, even for a large size power plant when all other factors are optimum for the shift in species. Most real cases will not be readily altered to a measurable extent.

**FIGURE 5. ALGAL POPULATION
SHIFTS WITH TEMPERATURE**

One of the more sensitive mechanisms for detecting small, incremental biological changes is through the measurement of species diversity. These and other pertinent biological, chemical and physical parameters should be obtained as a part of an environmental baseline position prior to plant operation.

Following the development of a systematic understanding of the aquatic ecology from the environmental baseline data, projections can be made regarding the effects of heated discharge into the system. Where the projections show no detrimental effects from the heated discharge, the water system should be used to serve society's needs in the same way that other natural resources can be utilized without damage if carefully managed. Where the projections indicate significant and measurable damage to the ecosystem, alternate cooling systems for nuclear plants can be incorporated. Each of these alternate cooling systems, however, has its own specific effects on the environment, on the plant operation, efficiency, costs and on the total problem of allocation of resources.

Environmental Investigation of Discharge Heat: The application of quantitative analysis, theoretical and empirical, is just emerging as a means for identifying and predicting the numerical relationships among natural biological systems.

Systems Approach: A meaningful, systematic environmental investigation into the effects of thermal discharges should encompass three important phases:

1. Obtain baseline data on the environmental system.
2. Evaluate these data, projecting the possible environmental stresses that may develop and provide recommendations for corrective action where required.
3. Monitor during plant operation for actual alteration of the aquatic ecosystem.

In considering the cost and availability of manpower that can be applied to environmental studies, it is abundantly clear that the program cannot and should not be designed to find out "all about everything." Rather, the investigation should

be directed toward an analysis of the life support systems for key species. Planning the investigative program is a vitally important step in that each bit of data acquired should fit into the total plan and pass the simple test; "What will I do with this data when I get it?"

One systems engineering technique finding use in analyzing the effects of thermal discharge is the development of a logic diagram of the type often used by reliability engineers in fault analyses. A simplified diagram developed for fish is shown in Figure 6. Some of the salient points that one could obtain from the use of such a diagram are:

1. Critical factors in the fault tree that have high probabilities for influencing mortality and morbidity.
2. Factors that man cannot control in ecosystem management.
3. Identification of critical areas that are sensitive to the stresses of heat.
4. Identification of critical areas associated with pollutants that are not from the power plant.

The concept is particularly valuable in analyzing actual or potential fish kill situations. Through the forced considerations of all possible reasons for fish kill, including those that may be instigated by waste heat, an orderly plan of investigation and assessment can be made with a resultant assignment of probabilities to each step on the fault analysis.

It is important to recognize that an understanding of the interaction of thermal discharges with aquatic life requires expertise in the disciplines of thermodynamics, hydrodynamics, chemistry, limnology, biology, toxicology and perhaps, most importantly, systems analysis to integrate the various parts of the problem into a meaningful and useful total concept.

Beneficial Uses of Waste Heat: The continued growth in demand for electricity affords an interesting new opportunity in utilizing waste heat in beneficial projects which, in turn, offers a superior alternate in the management of natural ecosystems. In general, it appears that the most promising projects for utilizing waste heat

FIGURE 6. FAULT ANALYSIS FOR FISH MORTALITY

are biological and biochemical processes, with chemical and physical processes being of descending merit. Controlled heated water has been found to be advantageous in various forms of fish culture (particularly shell fish) and in agriculture to extend growing seasons. In both cases growth is accelerated with heated water.

In a current study Westinghouse is investigating the beneficial uses of low grade heat in compatible urban systems. One such example is the use of discharge heat to increase the rate and effectiveness of secondary sewage treatment processes. The activated sludge process for sewage treatment can be induced to proceed at almost double its normal rate by increasing the temperature approximately 25°F.

Alternatively, treated sewage water effluent may be used as make up to cooling towers where the nutrients can be substantially concentrated by the evaporation of diluent water as a step in nutrient recovery and recycle in man's ecosystem.

CONCLUSIONS

Pressurized Water Reactors release small quantities of radioisotopes to the environment during normal plant operation. The dilution, distribution and possible reconcentration of these isotopes in the environment have been examined for the case of fresh water river systems, cooling ponds and coastal sites and found to be far below internationally established standards and will pose no problem to public health nor the natural ecosystem.

The discharge of heated water into natural water systems has not developed any major problems yet, but continued growth in electrical power production may cause damaging environmental stresses to occur in some areas. Through a detailed examination of the physical, chemical and biological factors integrated in a total systems analysis an assessment of environmental impact of discharge heat can be made on a case-by-case basis. Through environmental management, society will be able to utilize the heat dissipation capability of many bodies of water without significantly altering the natural ecosystem.

Processes for utilizing discharge heat in aquaculture, agriculture and urban systems offer further opportunities whereby the benefits of nuclear power may be extended in the years ahead.

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FIGURES

- 1 Typical Region for Single Reactor Site**
- 2 Annual Exposure as a Function of Assumed Reactor Fuel Failure and Distance from the Site Boundary**
- 3 Annual Exposure as a Function of Distance from the Site Boundary**
- 4 Aquatic Communities Classified on Basis of Metabolism**
- 5 Algal Population Shifts with Temperature**
- 6 Fault Analysis for Fish Mortality**