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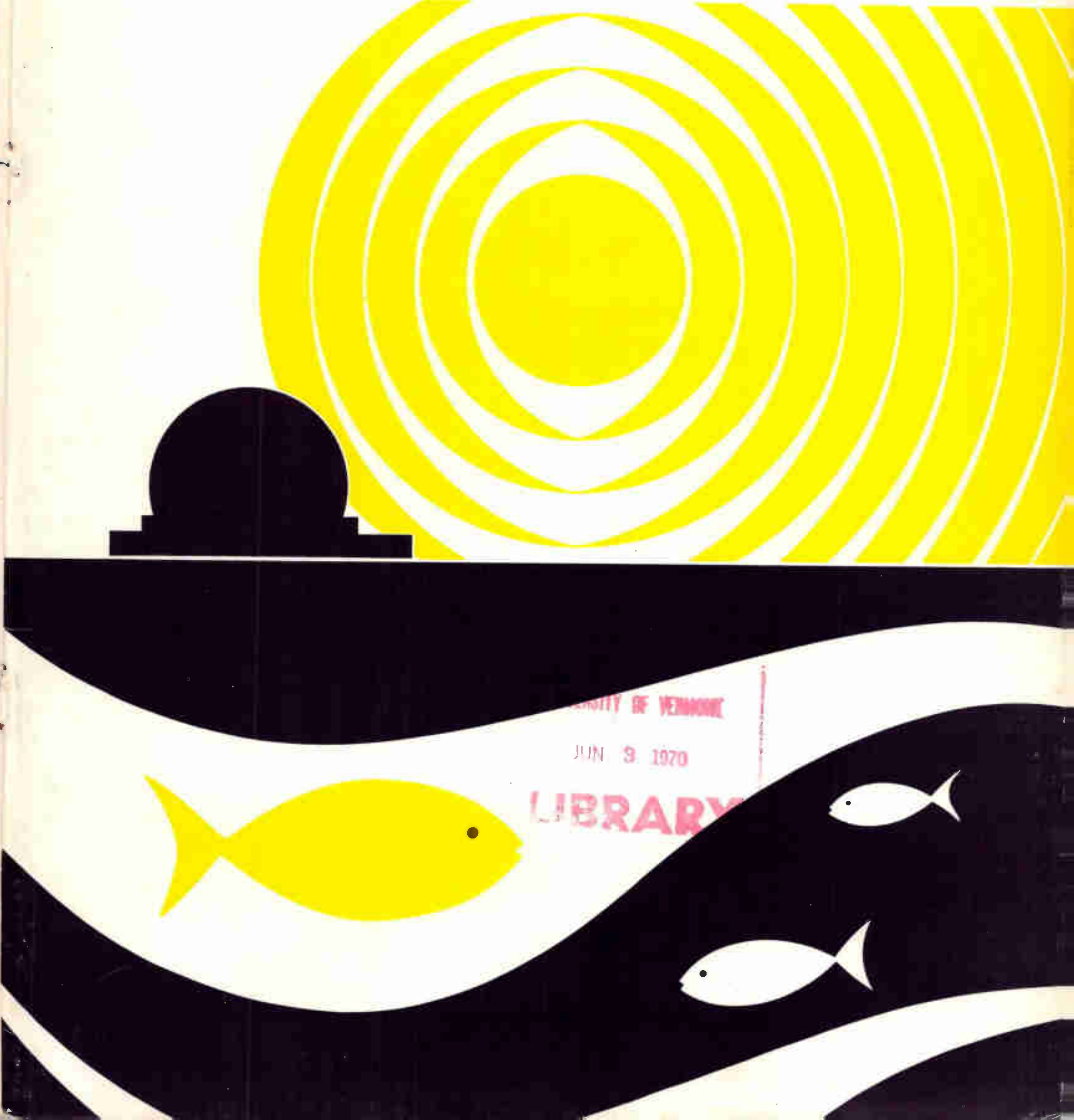

Submarine Rescue Vessel Can Be Transported By Air

A deep-diving submersible equipped to rescue the crews of submarines sunk in as much as 5000 feet of water was launched recently at San Diego, California. The vessel is transportable by air for fast response to an emergency anywhere in the world.

In an exercise that duplicated much of the travel sequence of an actual rescue mission, the vessel and its support equipment were put aboard three C-141 jet transports at Moffett Naval Air Station in northern California, next to the Lockheed Missiles and Space Company plant where it was built. It was flown to North Island Naval Air Station in San Diego and then transferred by trucks to Harbor Island for the launch.

The propulsion and maneuvering equipment needed for precise positioning over a stricken submarine's escape hatch were supplied by Westinghouse. For more information, see page 94.

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Front cover: The environmental aspects of steam electric power plants are discussed in this issue's feature article. Clean air and clean water are the environmental goals depicted by artist Tom Ruddy in his cover design.

Back cover: Second reduction gears, or "bull gears," for two types of ship propulsion gearing were photographed in manufacture at the Marine Division, Sunnyvale, California. The 14-foot gear in the foreground will be installed aboard one of eight containerships being built at Litton Industries' new automated shipyard for American President Lines and Farrell Lines. The smaller one in the background, part of a "nested" gear arrangement, will be installed in an older ship recently converted to a containership for Sea-Land Service, Inc.

Electric Power Generation and the Environment

James H. Wright

Environmental pollution has caught the attention of almost everyone, and it is beginning to generate the remedial efforts that the problem has long deserved. The generation of electric power epitomizes our environmental predicament. If we are to progress socially and economically, we must continue to increase power generating capacity. However, power generation is an energy conversion process that at present and in the foreseeable future inherently includes production of such undesirable waste products as sulfur dioxide, unused heat, and radioisotopes.

The first step in solving the environmental problem is to define its immediacy and seriousness carefully. As in any problem, those factors determine the timetable for and magnitude of the remedial measures required.

1—The Environmental Crisis

The high standard of living enjoyed in the United States today is due largely to rapid technological accomplishments pursued within a framework of conventional economics. The chief consideration of this kind of economics is the rate of gain anticipated relative to the resources committed. Unfortunately, the interest in optimizing financial objectives seldom has included adequate attention to the undesirable side effects of technological progress on the natural environment. The rising anxiety for the deterioration in the natural environment is not surprising—in fact, this concern is long overdue.

Having reached a relatively high level of affluence, we should seriously consider implementing a program of environmental improvement that will minimize or eliminate undesirable environmental effects while maintaining and advancing our standard of living. The new economics required to accomplish this aim must be concerned with a financial evaluation of a project, including the total effects on the natural resources. For example, to establish a new industrial plant, we commit money for land, construction, labor, equipment, and operating personnel. But, in the process, we also consume or contaminate some portion of our natural resources. We have, thereby, accumulated some heavily overdrawn accounts with nature. For example, the thousands of miles of streams that are contaminated with acid mine drainage exemplify the fact that, by *today's* standards, *the price of coal in the past was too cheap*. That price simply did not include the cost of preventing serious, lasting, environmental damage.

This is not meant to imply that all development that causes environmental change should be stopped. For many places in the world with bright blue skies overhead, a little smoke in the air would be a welcome sight if it meant a significant decrease in the abject poverty of the area. The environmental crisis in the United States today has come about because the total costs of all resources consumed or contaminated by the development of industry have not been included in the economic evaluation. This nation, with 6 percent of the world's population, consumes 35 percent of the fossil fuels available and produces more than its share of the pollution. In the past, improvement of the standard of living was a prime motivator; at this time, an improved standard of living is still of concern but this nation must now take better care of its natural resources and environment.

In the economic evaluation of a power plant, for example, one should realize that with its construction will come the consumption of land that is being used for something else, the use of air and water, and the discharge of by-products to the land, air, or water. Among the by-products are heat, gases, particulate matter, and radioactive material. While these aspects of power production on the natural environment may seem undesirable, evaluation of the benefits that can accrue from such a plant to the economic and social environment also must be considered. Ample electric power permits better use of raw materials, labor, and investment capital toward the end of producing useful goods, the sale of which increases the financial stability and general well-being of the locality. Electric power can take up many of the physical burdens that would otherwise have to be borne manually and can provide additional safety for the residents through street and highway lighting, better hospital facilities, and improved recreation. The *new economics* would realistically include all these factors in establishing the total cost of a project.

The Growing Demand for Electric Power Versus Growing Pollution

The combination of rapid population growth with an increasing rate of per capita power consumption indicates that generating capacity should double every decade to satisfy future economic and social needs (Fig. 1). To meet this rising demand for electric power, modern technology provides three basic types of power plants: hydroelectric, gas-turbine, and steam-turbine.

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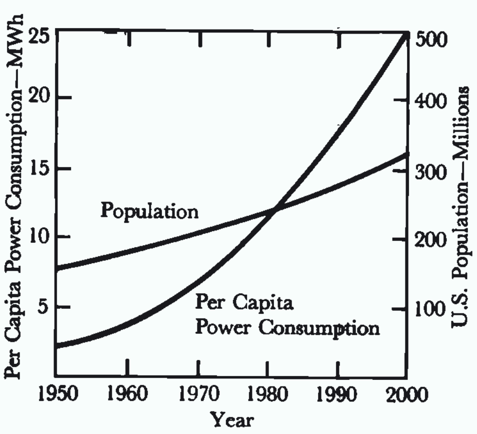
According to testimony before the Joint Committee on Atomic Energy last fall (1969), hydroelectric plants produce about 15 percent of the total generating capacity.[1] However, since the number of hydro-plant sites created by nature is limited, additional capacity from this source is not likely to be forthcoming. Gas-turbine plants, while well suited for peaking and reserve duty, are not economical for baseload operation, and any significant increase in the relative number (presently 4.7 percent) is unlikely. Consequently, the bulk of new capacity will be provided by steam-turbine plants, and the future levels of environmental pollution will be in part associated with this form of power generation.

This article, therefore, is concerned with the environmental impact of steam electric power generation plants, both the *nuclear pressurized-water* (PWR) type and *fossil-fueled.* When making an assessment of what is happening and will happen to our environment, the following questions come to mind:

1) How do the emissions from power plants affect the health and well being of the general public?
2) What are the standards and environmental yardsticks to which we can refer these emissions?
3) What are the present levels of emissions from power plants and how do they relate to the total pollution problem?
4) What devices and techniques are available for improvement now and what will be needed in the future?

Only through such questions and answers can a *quantitative* assessment be made that leads to a better *quality* environment.



1—The demand for electric power is a function of both population growth and increasing per capita consumption, which result in an approximate doubling of total power requirements each decade.

From nuclear power plants, we have the emission of radioisotopes to our air and water environment. From fossil-fueled plants, we have the emission of particulate matter and noxious gases to the atmosphere. From both types, we have the addition of heat to our waters.

2—Environmental Radiation, Radiation Standards, and PWR Plant Emission

The direct radiation emitted during the nuclear power generation process is carefully contained by shielding around the reactor and presents no hazard to the public. However, minor amounts of the radioisotopes produced during the nuclear process are released from the reactor to the environment.

The most practical environmental radiation base line for helping us understand the significance of releases of radioactivity from nuclear power plants is called *natural background.* Natural background creates a field of ionizing radiation, and people exposed to this field receive a radiation dose.. (For simplicity of discussion, the words "exposure" and "dose" are used interchangeably in this article.)

Radiation from cosmic ray interactions and the inherent radiation of terrestial materials such as rocks, buildings, and food contribute to the exposure of man by this natural background. Typical background exposures result in radiation doses to local residents in the range of 100 to 200 millirem/year. However, much larger exposures have been observed in certain locations as noted in Table I.

Establishing Radiation Standards

As the scientific community of the world began experimenting with radioactive substances and X-ray equipment, it was recognized that exposure to large amounts of ionizing radiation could produce deleterious effects on the human body. This realization lead to the establishment of guidelines for levels of environmental radiation, i.e., radiation standards.

In 1928, the International Commission on Radiological Protection (ICRP) was set up to establish radiation standards, followed in 1929 by establishment of the U. S. National Committee on Radiation Protection and Measurements (NCRP). The former was set up by the International Congress of Radiology, whereas the latter initially included medical societies, X-ray equipment manufacturers, and the National Bureau of Standards. Although both bodies initially were interested in occupational exposure, more recently they have made recommendations for nonoccupational exposures. Both groups have established their recommendations for human exposure limits from experimental animal data, accidental exposures of human beings, intentional exposure of human beings for diagnostic and therapeutic purposes, and casualties from atomic bombs of World War II. Neither organization has any regulatory authority, so they serve as independent scientific evaluators of radiation data.

In 1959, the Federal Radiation Council (FRC) was established to provide a federal policy on human radiation exposure. In establishing the Federal Guidelines on Radiation, the Federal Radiation Council used three basic concepts: The biological risk of man-made radiation; the biological risk of man-made radiation compared to radiation from natural sources; and the benefits to be derived from radiation use.

The FRC standards summarized in Table II establish the recommended dose limits above background for the categories occupational and nonoccupational. The most limiting occupational dose, 5 rem in one year for the body organs shown in the first line, is for the most radiation-sensitive parts of the body. Other body organs, such as the hands or feet, are allowed as much as 75 rem in one year because of lower radiation sensitivity.

It was felt that the dose of 5 rem per year was too high for an individual in the

Glossary of Terms

Roentgen (R)—The original unit of radiation. It is the amount of X or gamma radiation that produces in one cubic centimeter of standard dry air ionization equal to one electrostatic unit of charge. It is used to describe the radiation field to which one may be exposed.

Rad (*r*adiation *a*bsorbed *d*ose)—The quantity of radiation that delivers 100 ergs of energy to 1 gram of substance (almost equivalent to a roentgen when referred to body tissue).

Rem (*r*oentgen *e*quivalent, *m*an)—A biological (rather than a physical) unit of radiation damage, the quantity of radiation that is equivalent in biological damage to 1 rad of 250 kilovolt peak X rays.

Curie (Ci)—A measure of radioactivity. One curie is the amount of any radioactive nuclide that undergoes 37 billion transformations per second.

Half-life—The average time required for half the atoms of an unstable nuclide to transform.

Dose—A measure of the energy actually absorbed in tissue by interactions with ionizing radiation.

Exposure—A measure of X or gamma radiation at any point, used to describe the energy of the radiation *field* outside of the body.

general population for several reasons:

1) Children are more radiosensitive and are not included in the occupationally exposed category.

2) The lifetime dose to an individual in the public should be less than the lifetime occupational dose.

3) There are some radiation effects that have a latent period of as much as 30 years after exposure before they become noticeable. Exposure to radiation at pre-employment ages gives more time for these effects to manifest themselves in the general population.

4) Workers in any industry undergo pre-employment selection, so their health is good and thereby their susceptibility to radiation injury is probably less than that of the population at large.

5) Individuals have a choice of occupations and in principle are accepting some voluntary risk by working in the nuclear industry.

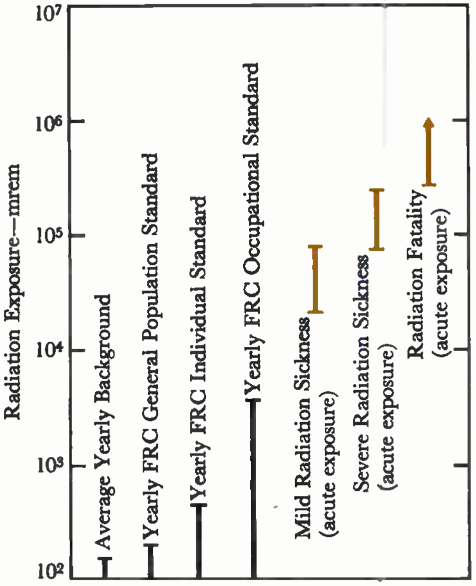
6) Considerations of the uncertainties of population genetic damage caused by radiation make it desirable to limit gonadal exposure to the whole population.

Considering these factors, the FRC standards specify that no individual in the public should receive more than 500 mrem/year, one-tenth of the occupational exposure. The FRC further assumed that the health and susceptibility to radiation effects of the general population may vary by a factor of three. Consequently,

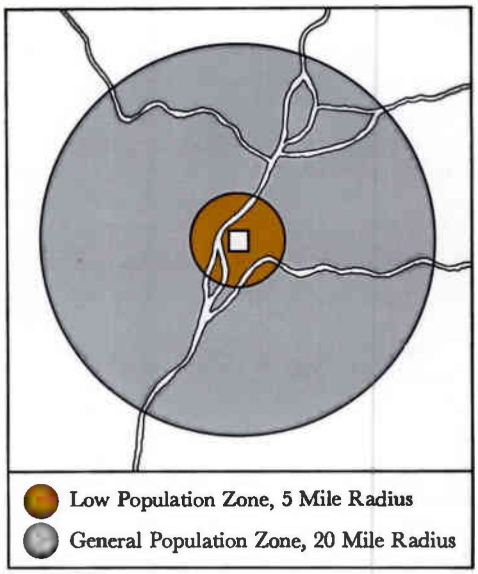
Table I. Background Radiation Doses, mrem/year

Terrestrial Radiation	
Kerala, India	1300
Granite areas, France	265
USA	90
Cosmic Rays	
At sea level	*28
Denver, Colorado	70
At 20,000 feet	375
House Construction Materials	
Wood	50-65
Brick	75-90
Stone	85-130
Natural Radioactivity in the Body	25

*From secondary radiation produced by high-altitude cosmic ray interactions.



2—Acceptable limits of radiation exposure above background level are specified by the Federal Radiation Council. These chronic exposure limits are set far below levels that have produced detectable effects. Shown in contrast are acute exposure levels that produce radiation sickness and death.



3—Geographical model of a 1000-MW pressurized water nuclear plant on a river near a metropolitan area is used to calculate design-basis and expected radiation exposure levels (Table III).

170 mrem/year was chosen as more prudent for general safety.

From the FRC standards, the U.S. Atomic Energy Commission (AEC) in document 10CFR, Part 20, has related these standards to permissible concentrations of radioisotopes in the environment. These concentration guidelines, sometimes called secondary standards, are such that an individual who is continuously exposed to the isotopes, by drinking water, breathing air, and eating food containing them, will not exceed the FRC recommended dose limit.

Hence, the FRC provides consideration of the public-health, social, economic, defense, labor, natural resources, and agricultural benefit and risk factors, as well as the scientific factors, in the development of guidance for federal agencies. *Furthermore, there is the opportunity in this process for anyone to introduce new facts, evidence, or opinions for evaluation in the same careful way.*

Radiation and the Human Body

To properly interpret these standards, we must consider the body as a biochemical system and determine how radiation affects it. In the simplest terms, the human body is a complex of biologically active chemicals and is capable of reproducing itself.

Radiation can affect these complex chemicals by ionization, which may break covalent bonds (the most common type) or by physical displacement of atoms when they are bombarded by massive particles such as neutrons or alpha particles. The effect of radiation depends on which type of body cells are affected, somatic or germ cells.

Somatic cells produce daughter cells (by mitotic division) that have identical chromosome and deoxyribonucleic acid (DNA) content and a specific function, i.e., stomach tissue, lung tissue, skin, fingernails, etc. Germ cells also divide (meiotic division), producing gametes containing half the number of chromosomes of somatic cells. Combination of these gametes from the male and female, spermatozoa and ova respectively, yields new individuals with the full chromosome complement, and the life cycle starts over.

Clearly, radiation damage to somatic cells affects only a given individual and cannot be passed on to succeeding generations. On the microscopic scale, the detrimental effects of radiation to somatic cells can cause immediate cell death, loss of function and thereby malignant growth, and/or minor changes in the DNA such that the effects do not appear until late in life. The effects of cell death from radiation on the total organism, man, depends on the number of cells killed and the body's ability to repair itself. That is to say, the body's ability to repair itself is strongly dependent on the total dose and dose rate. Effective ranges of acute dose, i.e., instantaneous doses, for clinically observable effects on man relative to the FRC standards are shown in Fig. 2. Using mild radiation sickness as an example, there will be practically no individuals with symptoms of radiation sickness at 20,000 mrem whole-body dose, while practically all will have symptoms at 80,000 mrem. The difference between the FRC limits and the dose required for the onset of clinically observable symptoms shows the degree of conservatism in the standards.

The occurrence of late somatic effects of radiation, e.g., various cancers or early aging, have been statistically demonstrated for individuals who received doses from 100 to 500 rem, and the incidence of these effects appears to be linear with dose in this range. The two major and closely related questions that arise here are: What is the relationship between dose and incidence of cancer at lower total doses, and is there a dose of radiation (threshold) below which cancer will not be induced?

One hypothesis used in evaluating radiation damage assumes that all radiation is hazardous and that there is a

Table II. Summary of FRC Standards, Radiation Dose Limits above Background

Occupational	*Condition*	*Dose Limit (rem)*
Whole body, head, trunk, blood-forming organs, gonads, lens of eye	Year	5
Skin and thyroid	Year	30
Hands, forearms, feet, ankles	Year	75
Other organs or soft tissue	Year	15
Bone	Body burden	0.1 μgram radium-226 or biological equivalent gives 28 rem/year
Nonoccupational		
Individual	Year	0.5 whole body or gonads
General population	30 years	5 (0.170 per year)

Table III. Annual Dose from Single Plant, mrem/year

		Site Boundary	*Low Pop. Zone (5 miles)*	*General Pop. Zone (20 miles)*
FRC recommended maximum	Air and Water*	500	170	170
Design basis (1% fuel leak)	Air	5.0000	0.1040	0.0156
	Water*	0.2055	0.0103	0.0093
		5.2055	0.1143	0.0249
Actual expected	Air	0.0063	0.0001	0.0000
	Water*	0.0435	0.0022	0.0020
		0.0498	0.0023	0.0020

*Includes food chain.

linear relationship between dose and effect. However, at low doses, the effects of radiation are masked by the possibility that the incidence of cancer may be from other causes. Detailed experiments with animals have indicated threshold doses, but their application to humans has been interpreted with care, since cancers and tumors are specific to species.

The concept of a threshold dose has been demonstrated to date in humans with doses to the bone from the isotope radium-226. From the accidental ingestion of radium by watch dial painters during the early 1940's, it was found that many of the workers developed leukemia and bone carcinoma. However, those persons whose bodies contained less than 0.5 microgram of radium have shown no latent effects. This is clearly indicative of a threshold for somatic effects. To be conservative, the standard of 0.1 microgram is presently used.

Evidence also exists for both the linearity of effect with dose and the threshold concept for genetic damage. However, experimentation and proof of either concept is complicated by the overwhelming number of possible combinations of the genetic material, even without looking for variations due to radiation effects.

The major units of hereditary material are called chromosomes, with 23 donated by the male and the female toward the full complement of 46 in man. The next smallest unit, the gene, a portion of the chromosome, has been identified with physical traits, such as eye color, hair color, etc. The genes themselves are arrangements of some 20 different amino acids that make up the DNA molecules. When permanent changes occur on any level of the genetic code, they are passed on to succeeding generations and are called mutations. Note that a mutation caused by radiation is no different from a mutation from any other cause; i.e., radiation only affects the mutation rate and not the kind of mutations.

Because the physical expression of a mutation may not occur for many generations, research for the effects of genetic alterations requires both large populations and many generations. Since the probability of genetic damage at low doses is very low, large populations are required to get meaningful data. Dr. W. L. Russell of Oakridge National Laboratory has conducted experiments over the past 20 years with about a million mice to determine the effect of dose and dose rate on genetic aberrations. Even with this large number of mice, reliable data are available only down to exposures of 86 roentgen, delivered at a rate of 10 R per week. The FRC standard is 5 rem in 30 years (170 mrem/year), which if spread out uniformly, provides a weekly rate of only 0.0033 mrem. Therefore, the experimental data on mice is at total integrated doses 20 times the FRC standard and at a dose rate 3000 times greater.

Dr. Russell's findings are as follows:

1) When radiation dose is spread out in time, i.e., lower dose rates, less genetic damage is produced.

2) For all practical purposes, *there is a threshold for radiation effects in female mice.* At the lowest total dose and dose rate tested, the mutation frequency in females was not significantly higher than the frequency for spontaneous mutations.

3) On the other hand, mutation frequencies in male mice *do not exhibit a threshold.* However, the number of mutations that occurred is a factor of six lower than the number used by the FRC in their assessment of genetic risk for the standards.

It has been estimated that similar experiments for humans would require a population sample of 100 million people for a period of 500 years to get good statistical evidence of low-level genetic effects from a 170 mrem/year incremental dose. This is because, as an upper limit and after many generations, the genetic effect would be expressed in only 6 persons in a 100,000 population.

In summary, while there may be a no-threshold relationship for genetic damage, the FRC standards were set conservatively by a linear extrapolation of data from high acute doses to the low dose range, neglecting the fact that the body will repair itself at much lower dose rates. Further conservatism occurs when the assumption is made that each mutant formed by radiation eventually leads to a genetic death, which is obviously not true.

Radioactivity from PWR Power Plants

To determine the existence or magnitude of public health problems that might result from locating nuclear power plants in a given area, it is important to determine the average exposure levels that might result to the general population from the plants. The information used in this article was obtained from pressurized water reactors (PWR's) designed by Westinghouse and operated by many electric utility companies.

In the past, the problem of public exposure to radiation from reactor effluents has been studied for two situations: exposure to the general population following hypothetical accidents; and exposure at the site boundary during normal plant operation.

For the first situation, conditions are still valid today. For the second situation, however, the public exposure must be determined for the *general* population, not just a *single* individual as in past calculations. The general population may be located at varying distances from the plant sites. To determine the *average* exposure from a nuclear plant on the general population, a set of *most probable conditions* must be used. These most probable conditions will be applied to the following three related sources of radiation exposure to the general public from the use of nuclear power: exposure to the general public from a single nuclear plant; exposure to the general public from multiple plants; and long-term exposure to world populations from the total nuclear cycle.

Radiation Exposure from a Single Plant—A simple geographical model of a 1000-MWe nuclear plant on a river system near a metropolitan area is shown in Fig. 3. Radioisotope releases for a typical PWR plant of present design are used in the calculations. The results of these calculations are presented in Table III for recommended allowable exposure, design-basis exposure, and anticipated exposure versus the location: site boundary, and low and general population zones

Table IV. Liquid Releases on a Design Basis from a PWR

Isotope	*Half-Life*	*Activity in Fuel, 1 Year Operation 1 Day Decay (kCi/MWt)*	*Fuel Activity, 3582 MWt (MCi)*	*Primary Coolant Activity (Ci)*	*Annual Release from Waste Disposal System (μCi)*	*Condenser Discharge Concentration (μCi/cc)*	*Max Permissible Concentration (Water), Unrestricted Area Total Body (μCi/cc)*
H-3	12.3 yr	0.0043	0.013	2183	5.68×10^{9}	3.8×10^{-6}	5×10^{-3}
Mn-54*	300 days			0.20	1.19	0.79×10^{-15}	8×10^{-4}
Co-58*	71 days			6.4	36.2	2.41×10^{-14}	4×10^{-4}
Fe-59*	45 days			0.27			
Co-60*	5.2 yr			0.19	4.27	2.85×10^{-15}	1×10^{-4}
Sr-89	50.5 days	39	140	1.48	14.7	9.8×10^{-15}	7×10^{-5}
Sr-90	27.7 yr	1.2	4.30	0.044	0.44	3×10^{-16}	4×10^{-7}
Y-90	64.8 hr	0.9	3.22	0.06	0.51	3.4×10^{-16}	3.0
Y-91	57.5 days	52.4	188	0.26	25.9	1.73×10^{-14}	0.2
Mo-99	67 hr	40	143	1175	1.08×10^{-4}	0.72×10^{-11}	8×10^{-4}
I-131	81 days	23	82.5	828	8.65×10^{2}	0.58×10^{-11}	2×10^{-4}
Cs-134	2.3 yr	0.29	0.108	95.2	3.19×10^{2}	2.12×10^{-12}	9×10^{-6}
Te-132	78 hr	30.1	108	91.5	9.1×10^{2}	0.0607×10^{-12}	5×10^{-4}
I-133	20.5 hr	26	93.0	1320	1.09×10^{4}	0.72×10^{-11}	9×10^{-4}
Cs-136	13 days	0.15	0.537	14.1	1.38×10^{2}	0.92×10^{-13}	9×10^{-5}
Cs-137	27 yr	1.3	4.65	515	5.15×10^{2}	3.43×10^{-12}	2×10^{-5}
Ba-140	12.8 days	48	172	0.08	3.49	2.33×10^{-15}	5×10^{-4}
La-140	40.5 hr	36	129	0.31	3.20	2.13×10^{-15}	2.0
Ce-144	290 days	30	107	1.06	12.45	0.83×10^{-14}	3×10^{-2}

*Corrosion products

Table V. Gaseous Releases on a Design Basis from a PWR[1]

Isotope	*Half-Life*	*Activity in Fuel, 1 Year Operation 1 Day Decay (kCi/MWt)*	*Fuel Activity 3582 MWt (MCi)*	*Primary Coolant Activity (Ci)*	*Annual Release from Holdup Tanks*[2] *(Ci)*	*Max Permissible Concentration (Air), Unrestricted Area Total Body (μCi/cc)*
Kr-85	10.4 yr	0.1	0.358	2313	6000	3×10^{-7}
Kr-85m	4.4 hr	0.2	0.716	556	Negligible	10^{-7}
Kr-87	78 min	0.0	0.0	378	Negligible	2×10^{-8}
Kr-88	2.8 hr	0.1	0.358	1369	Negligible	[3]
Xe-133	5.27 days	47	168.40	93,047	5500	3×10^{-7}
Xe-135	9.2 hr	14	50.15	2481	Negligible	10^{-7}
Xe-138	17 min	0.0	0	1750	Negligible	[3]

[1] Sequoyah Nuclear Plant, Preliminary Safety Analysis Report, prepared for Tennessee Valley Authority by Westinghouse Electric Corporation.

[2] Based on 45-day holdup before release.

[3] No standard given in AEC 10 CFR Part 20.

assumed to be 5 and 20 miles, respectively, from the reactor plant. The total body is the organ of reference.

The design-basis exposure (Table III) at the site boundary is roughly a factor of 100 below FRC guidelines and a factor of almost 100 higher than would actually be anticipated. In the low population zone five miles downwind and downstream from the plant, the ratio between FRC guideline exposure limits and design-basis exposure is a factor of more than 1000. The actual anticipated exposure in this region is roughly a factor of 50 below the design basis. The same general comparisons can be made with the general population zone 20 miles away, where the anticipated exposure is about 0.00001 of the FRC guidelines. Therefore, the total whole-body exposure to the general public from a single plant is anticipated to be no greater than 0.05 mrem/year and probably in the range of 0.002 mrem/year. The analysis of individual body organs indicates that their exposure is at least an order of magnitude below the total body exposure.

To interpret these results and assess their sensitivity to change, it is necessary to identify the assumptions and calculation methods used.

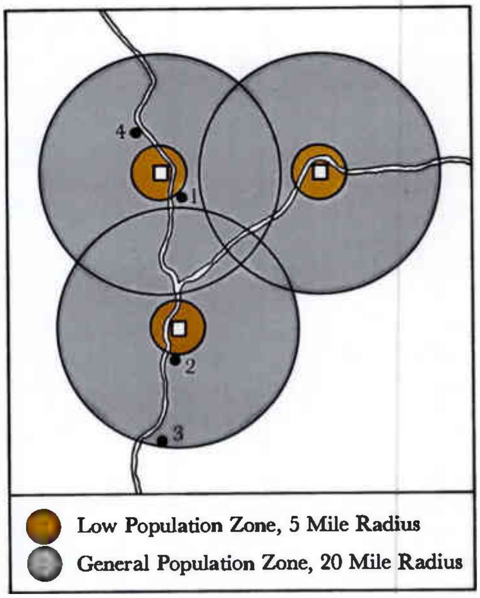
The PWR plant releases low levels of radioactivity to the air and to condenser water. Liquid discharges are first processed through the radiation waste system, which removes a large percentage of each radioisotope except tritium. The typical design basis for the production and release of fission products includes the assumption of a one-percent fuel failure and an operational decontamination factor of the radiation waste system. The gaseous discharge design basis includes the assumption of one percent fuel failure and a 45-day hold of all gaseous activity to eliminate short-lived radioisotopes. Source data for the foregoing calculations, shown in Tables IV and V, were obtained from the Preliminary Safety Analysis Report for the Sequoyah plant.

The data on the *actually expected* exposures were developed by scaling data from presently operating PWR's of Westinghouse design. The anticipated release of gaseous fission products was obtained by comparing actual operation with design basis at these reactors. Their experiences have been fairly uniform and show that the one percent fuel failure basis gives an overestimate of gaseous releases by a factor of 800 or more. Therefore, gaseous releases for the expected exposure calculations were reduced by this factor of 800 from design-basis releases.

The calculation of exposure from airborne activity was based on submersion in a semihemispherical infinite cloud of the radioactive gases. The local concentrations of radioactivity were obtained by procedures outlined by Pasquill.[2] A ground-level discharge was assumed with stable, neutral, and unstable atmospheric conditions occurring 40, 30, and 30 percent of the time, respectively, and 2, 6, and 3 m/sec average wind speeds, respectively. The annual average wind direction pattern was assumed to be ellipsoidal with a major/minor axis ratio of 2:1.

The liquid discharge exposure calculations include the categories of tritium releases and nontritium releases for analysis. The tritium design basis calculations contain the assumption that 30 percent of the ternary fission tritium is released to the coolant and that 100 percent of the tritium from boron carbide control rods and boric acid is produced and/or released in the coolant. The anticipated tritium release level includes the assumption, supported by limited data, that there will be substantially less tritium released with zirconium fuel cladding than with stainless steel. If this anticipated reduction does not occur, water exposures will be somewhat higher than those shown as "actual expected" and, as an upper limit, the anticipated water exposure levels will approach design-basis levels.

Nontritium liquid releases have not been as consistent among the three operating PWR's. For the "actual expected" release analysis (Table III), it was assumed that nontritium activity was six times that given in the design basis. This factor of six was applied uniformly to all liquid isotopes except tritium. There may be some evidence that any excess activity



4—(*Above*) Geographical model of three 1000-MW nuclear plants is used to demonstrate radiation exposures at various locations in the vicinity of multiple plants (Table VI).

5—(*Right*) The radioactive exposure at the fence line of a PWR plant is a function of fuel failure (left). The design basis allows for one-percent fuel failure, but operating experience has indicated that the isotopic release is equivalent to about 0.01 percent fuel failure. Exposure to the general population then becomes a function of distance (right), quickly dropping to an insignificant level compared with natural background.

in the water above the one percent design basis is principally due to activated crud (corrosion products). If this is the case, the anticipated exposures from water and food chain concentrations will be slightly reduced.

The exposure from liquid releases has two components: exposure from direct intake of drinking water from the river and exposure from solids and water intake through aquatic foods. The direct water intake is based on a "standard man" who drinks 1200 cubic centimeters of water daily. The aquatic foods, which could include fin fish, mollusks, and crustacea associated with commercial salt-water fishing, were included in the calculations along with the appropriate isotopic reconcentration factors although the reactors are assumed to be located on a fresh-water system. The exposure from aquatic foods was substantially less than five percent of the water intake dose.

Radiation Exposure from Multiple Plants—The assumptions and calculation procedures are the same for the multi-plant model as for the previous case except for the zones of overlapping radiation. A simplified plan showing three large PWR plants in the same geographic region is shown in Fig. 4. Exposures are calculated at the four points shown:

1) Downstream 5 miles from one plant and about 20 miles upstream from two other plants.
2) Downstream from three plants and varying distances from each of the three plants.
3) Downstream from all three plants, essentially 20 miles or more from the nearest reactor power plant.
4) Upstream but within the air shed of all three plants.

The calculated exposures are shown for each point on the basis of design and anticipated values in Table VI. It can be noted that the incremental radiation exposures through all mechanisms provide, at most, an average "expected" exposure to the general public of 0.003 mrem/year and as little as 0.0001 mrem/year. This is extremely low compared to the allowable FRC guideline exposure from nonmedical man-made radiation of 170 mrem above background.

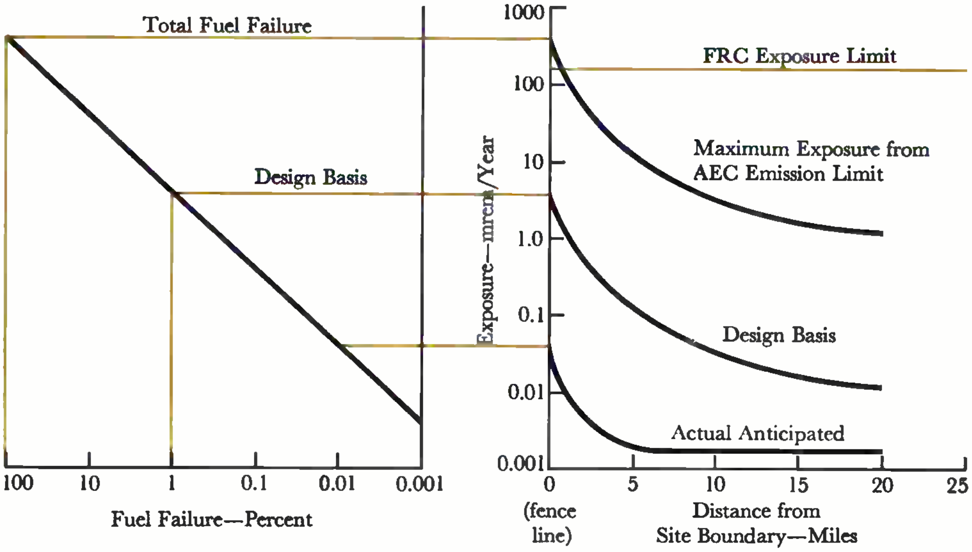
Table VI. Annual Dose from Multiple Plant Sites, mrem/year

		Zone 1	*Zone 2*	*Zone 3*	*Zone 4*
FRC recommended maximum	Air and Water*	170	170	170	170
Design basis (1% fuel leak)	Air Water*	0.1040 0.0103	0.1040 0.0144	0.0156 0.0139	0.1040 0.0000
		0.1143	0.1184	0.0295	0.1040
Actual expected	Air Water*	0.0001 0.0022	0.0001 0.0031	0.0000 0.0030	0.0001 0.0000
		0.0023	0.0032	0.0030	0.0001

*Includes food chain.

How the Standards Apply

One of the consistently misunderstood aspects of the regulations on radiation protection is the lack of differentiation between the roles of the FRC and the AEC in establishment and application of radiation protection standards for the general population. In review, the Federal Radiation Council has the responsibility for determining the exposure limits that the general population shall receive from all man-made sources exclusive of medical. This exposure limit is set at 170 mrem/year for the general population and a maximum nonoccupational single individual dose of 500 mrem/year. The AEC accepts FRC exposure standards and creates emission standards which are consistent with the FRC guidelines *only at the plant boundary*. The point often missed is that if nuclear plants were releasing the AEC emission limits, this would correspond to FRC exposure limits *only at the fenceline*. Hence, by dispersion in the environment, a move of 5 to 10 miles away from the plant would decrease the maximum possible exposure of the general population and fall into the range of 2 to 5 percent of the FRC limits. For the general population, then, the AEC emission limits provide a built-in automatic exposure reduction factor of approximately 20 to 50 below FRC limits. To illustrate this point, consider Fig. 5. On the left is shown exposure as a function of hypothetical fuel failure. Note that one percent in fuel failure corresponds to the exposure of 5 mrem/year as calculated for the single plant on a design



basis. It is correspondingly important to note that *a large PWR plant, with its 45-day gaseous holdup, would require essentially 100 percent fuel failure just to equal the AEC emission limit and the FRC exposure limit of 500 mrem/year at the fence line.*

Moving to the right side of Fig. 5, the exposure to the general population from the hypothetical case of 100-percent fuel failure decreases rapidly with distance to 1/20 to 1/50 of FRC exposure limits as previously mentioned. At the other extreme, the actual anticipated exposure (based on prior operational experience) results in a fenceline exposure of 0.05 mrem/year, a factor of 0.0001 of the AEC/FRC limits. This difference between allowable and expected exposures continues to increase, bringing the ratio of delivered exposure to FRC limits to approximately 0.00001.

What is the interpretation of the extremely low exposure to public risk when the FRC's linear no-threshold concept is applied? Between now and the year 2000, more than 20 million people in the U.S. will die from diseases associated with genetic defects. In this same time period, not a single genetic death would result from the radioactive discharges from pressurized water reactors, which includes the projected growth of the nuclear industry.

Long-Term Buildup in the Biosphere

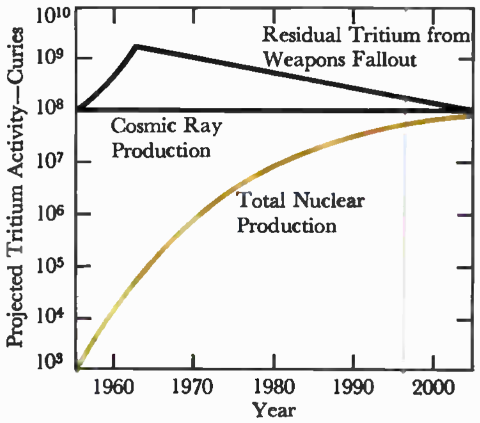
Considering the overall material balance of radioisotopes produced in the PWR plant, the net release of radioisotopes to the environment at the plant site is about one millionth of that produced during the fission reactions in the power production cycle. When the nuclear fuel has completed its function at the nuclear power plant, it is shipped to a fuel reprocessing plant. Those now in service provide extensive treatment of the gaseous and liquid effluents, removing large fractions of all radioisotopes except tritium and the noble gases krypton and xenon. The latter is largely removed from the gaseous effluent by means of the 45-day hold system that permits decay of most of the accumulated xenon in that period of time. However, the total gaseous release of radioactivity at the fuel reprocessing plants is on the order of 1000 times that released at the nuclear power plant reactors.

Both tritium and krypton have relatively long half-lives, on the order of 10 to 12 years, and outside of a minor tendency for tritium to concentrate in the oceans, there is no known or conceivable mechanism for reconcentration of these isotopes in nature above release levels. It would appear that they will tend, in time, to distribute more or less uniformly throughout the biosphere. While the planetary buildup of these radioactive materials from this source does not pose a short-term problem, it is pertinent to consider some other major sources so that the long-term situation may be evaluated for the purpose of determining what kind of additional radioactive waste retention systems may be required, and when.

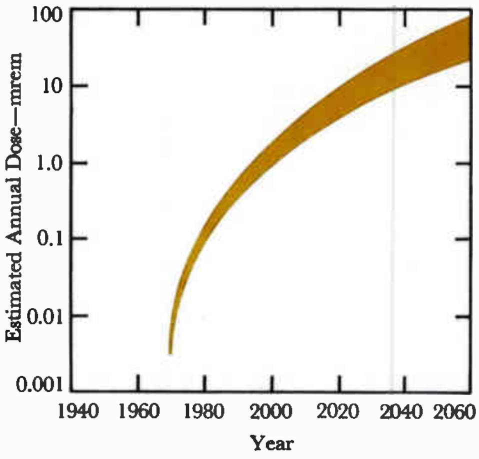
From an environmental standpoint, it is necessary to consider the release of these radioactive gases in terms of that which already exists in the atmosphere. Of the two considered above, tritium is of the greatest concern because of its ability to substitute chemically for the stable isotope of hydrogen in body tissues.

Reactions of cosmic ray protons with gaseous atoms in the upper atmosphere may include the production of electrons, neutrons, protons, mesons, and *tritons,* the nuclei of tritium. Each of these particles (if produced with sufficient kinetic energy, and most of them are) is capable of producing secondary reactions with other gaseous atoms. Tritium is not only an innovator but also a possible product of some of these reactions.

While the material that makes up the bulk of the cosmic ray flux striking the earth is derived from the flares associated with the sunspot activity and is composed of high-speed protons (hydrogen nuclei), a sizable portion of these protons are believed to be tritium nuclei. Before the atmospheric nuclear explosions conducted for military purposes, the tritium level derived from the natural sources described above had reached about 100 million curies in the atmosphere. Although the supply of new tritium is relatively constant as a result of the cosmic ray flux, it had not built past this



6—Cosmic ray production of tritium in the earth's atmosphere provides an equilibrium value of 100 million curies. Estimated tritium activity produced by nuclear power facilities in the year 2000 will also be 100 million curies, or approximately 6 percent of the maximum tritium activity present in 1963.



7—Within a century, average exposures to the world population from krypton-85 could reach 50 to 100 millirems if retention systems are not developed for fuel reprocessing plants.

level because of the natural tendency of the existing tritium in the atmosphere to decay with a half-life of about 12.4 years. The concentration of tritium in the rain of the troposphere due to cosmic activity alone ranges from 50,000 to over a million atoms per cubic centimeter of rain. The rate of tritium buildup in the atmosphere is subject to the sunspot cycles and shows an 11-year variation along with the aurora and general radio transmission capabilities, all of which are strongly affected by the stream-by of charged particles from the sun.

The present dose to each individual from tritium in the biosphere is 0.060 mrem per year, due largely to a peak load of tritium in the atmosphere. This peak level was reached in the early 1960's after the moratorium on atmospheric testing of nuclear devices was agreed on (Fig. 6). The hydrogen bomb testing that the moratorium terminated had raised the normal 100-million-curie level to 1700 million curies in a period of only a few years. The annual production rate of 8 million atoms of tritium per square-centimeter surface of the earth is simply not adequate to maintain the tritium level at this artificial level, so the overall concentration is slowly dropping and should reach the normal equilibrium level at about the year 2000. Roughly speaking, the concentration of tritium in the lower atmosphere is presently on the order of 50×10^{-15} curies per cubic meter of air. This level should drop even more rapidly than that in the upper atmosphere over the next decades because of the natural tendency of tritium to concentrate slightly in the ocean waters.

Conservatively, it is assumed for the projection of tritium releases that all future reactors are of present PWR design and all future reprocessing plants operate as at present. A continuing increase in electrical power requirements for the world is also assumed, with nuclear power accounting for half of the total electrical generation capacity of the world by the turn of the century and increasing still further in the years beyond. The resulting buildup of reactor-produced tritium, shown in Fig. 6, increases exponentially until it has reached the level of cosmic-ray-produced environmental tritium in the late 1980's and should, around the turn of the century, be equal to the residual tritium from the hydrogen weapons tests of the last two decades. After the year 2000, reactor-produced tritium could become the dominant source of tritium in the environment if it is not contained by that time, and the planetary exposure to the world population from all sources of tritium would be 0.002 mrem.

The krypton-85 content of the atmosphere is entirely derived from nuclear reactions. Present environmental concentrations result in a dose to man less than 0.1 percent of the combination background from cosmic rays and natural radioactivity. As noted by Dr. C. E. Larson (Commissioner, AEC), "The dose due to this long-lived krypton isotope is considerably less than the difference experienced in moving in or out of a major building."[1]

If current power production practices are extended to the year 2000, it is estimated that the exposure due to krypton-85 could increase to about 2 milliroentgen-years, or 1000 times that of the tritium, and about one percent of the radiation protection guides recommended by national and international standards groups. As shown in Fig. 7, the estimate for the annual individual dose would be between 50 and 100 mrem/year. While this level of dose is still within the international guidelines, it certainly would seem prudent to undertake the necessary corrective measures, particularly at reprocessing plants, to minimize the impact of nuclear energy on the total environment. The estimated buildup shown in Fig. 7 suggests that corrective action should be taken toward developing krypton retention systems before the turn of the century. This should be ample time, not only for development but also for incorporation of such systems into all reprocessing plants constructed after the present decade. Fowler and Voit[3] indicate that the present technological capabilities with cryogenic concentration of the krypton followed by solid absorption may be the most promising means for krypton management in the near future.

3—Air Pollution

The principal fossil fuels used for steam electric power generation are bituminous coal, residual oil, and natural gas, each with its own spectrum of air pollutants. Typical emissions of these pollutants, carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates, and hydrocarbons are shown in Table VII for a 1000-MWe station.

Emission of particulate matter, which ranges in particle size, is common to the use of all three fuels. These particles are the small incombustible solids that remain suspended in the combustion chamber and are forced out with the high-velocity flue gases. The oxides of sulfur, principally SO_2, are released primarily from residual oil and coal plants. The sulfur contained in oil and coal is oxidized to SO_2, which in turn may be oxidized to SO_3 (about 5 percent). Fixation of the oxides of nitrogen requires a series of reactions. Elemental nitrogen is available for reactions from the air in the furnace. At the high temperatures of the furnace wall, NO and NO_2 are readily formed. For the overall plant efficiency, it is desirable to get a clean flame at the highest possible temperature and to remove this heat at high transfer rates to the steam boiler. This quick heat removal fixes the oxides of nitrogen, a large part of which normally would decompose to nitrogen and oxygen in slower cooling processes.

Nationwide, the combustion of fossil fuels annually produces some 142 million tons of air pollutants, with power plants contributing 20 million tons, or about 13 percent of the total. For the individual pollutants, electric generating plants account for about 50 percent of the SO_x, about 20 percent of the NO_x, and about 10 percent of the emission of particulate matter.

On a regional basis, other sources of pollutants may completely dominate the environmental problem. For example, the Los Angeles Basin has its problem with photochemical smog from NO_x and hydrocarbon reactions, the principal pollutor being the automobile. Nationally, automobiles emit approximately half of the oxides of nitrogen.

Biological Aspects of Air Pollution

Episodes of severe air pollution have been recorded in various parts of the world that have resulted in death and severe sickness to segments of the population with diseases that make them susceptible to irritation by air pollutants—for example, chronic bronchitis and pulmonary emphysema. The significance of these episodes in Donora, Pennsylvania, in 1948 and in London in the years 1952, 1954, 1956, and 1957 is that they have been documented by epidemiological and post-mortem studies that definitely related morbidity and mortality to the levels of pollution. One striking fact from these cases, supported by laboratory experiments on animals and some humans, is that there is a synergistic effect with high concentrations of particulate matter and SO_2. Alone, SO_2 acts as a bronchial restrictor that can cause breathing problems, especially for those who already have a breathing impairment. In the presence of aerosols of ferrous iron, manganese, or vanadium, which may be present elementally in particulate matter, SO_2 and these aerosols react forming sulfuric acid. Sulfuric acid is a more severe irritant to the bronchial system and can penetrate deeper into the lungs. Therefore, combinations of particulate matter and SO_2 are potentially more damaging than either alone.

Setting of Standards

As with radiation, the question arises of what are the long-range effects of low levels of SO_2 and particulates on the health of the general population. Epidemiological studies conducted by the Department of Health, Education, and Welfare in many U.S. cities have lead to criteria that relate cause and effect, but the development of broad standards is still in its infancy. To date, HEW has published documents on air quality criteria for particulate matter[4] and sulfur dioxide.[5] A document on air quality criteria for the oxides of nitrogen is in preparation. Because of the previously mentioned synergistic effect of particulate matter and SO_2, HEW has listed in both published documents combinations of the two pollutants and probable effects.

These data, shown in Fig. 8, relate duration of exposure to SO_2 content without quoting the levels of particulate matter. The color portion represents mortality in excess of normal incidence, the grid area connotes reported health effects, and the shaded area represents concentrations with suspected health effects. Although this data is not very definite, it forms the basis of State regulatory limits that are submitted to the Department of HEW for review and approval. *Each State's air basin standards are regional in scope and limit the exposure to the general population, as do the FRC standards for environmental radioactivity. Similarly, emission standards for individual air pollutors are needed that are equivalent to the radiological emission standards as conceived and regulated by the AEC.* This problem is complicated by the variety of sources, some of which are mobile. The effort of establishing emission standards for air pollutants is today's challenge to the scientific and regulatory experts—the kind of challenge already accepted by the AEC for radiation emission standards.

Controlling Emissions from Power Plants

The most advanced and developed emission control devices are for particulate matter. The techniques, which have varying degrees of efficiency of collection and which are often used in combination are: centrifugal force (cyclone), filtration (fabric filters), charged fields (electrostatic precipitators), and gas scrubbers. The efficiency of collection depends on pressure drop across the device, operating temperature, and how well the devices are maintained by operating personnel.

From the point of view of total environment pollution, care must be taken in device selection so that we do not exchange an air pollution problem for a solid-waste disposal problem or a water pollution problem.

To control sulfur dioxide emission, three approaches are being used, none of which are complete answers to the problem: using coal that normally has low sulfur content, removing sulfur from the fuel before it is burned, and installing collection devices for sulfur dioxide after the fuel is burned.

Low-sulfur coal (one percent as compared to the nominal three percent) is available and being used for statutory reasons in two states. However, other industries, especially the metallurgical industry, also exert a high demand for this coal. Therefore, it is important to recognize that one-percent-sulfur coal provides only a short-term limited solution to the problem for two reasons: with electrical production doubling every 10 years, the total emission from increasing quantities of low-sulfur coal will become greater than that emitted from smaller quantities of higher-sulfur coal; and present U.S. reserves of low-sulfur coal cannot meet total demand.

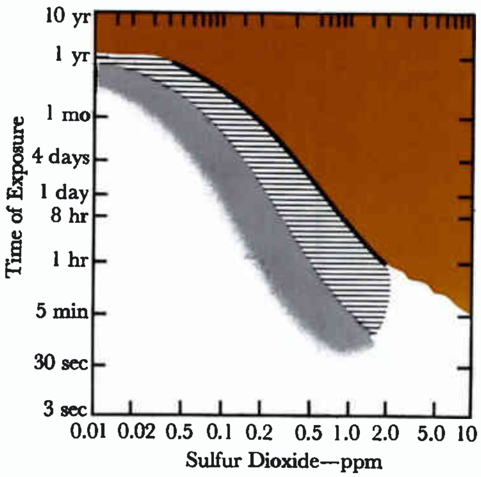
Some sulfur can be removed from coal before burning with existing technology. Sulfur occurs in coal in the pyrite form (FeS_2) and as complex organic compounds. The pyrite form can be removed by washing and grinding, leaving only the organic compounds, which are more difficult to remove. Preliminary results of research supported by the National Air Pollution Control Administration show

Table VII. Typical Annual Releases from 1000-MWe Fossil Fuel Stations, millions of pounds

	Coal[1]	*Oil*[2]	*Gas*[2]
Carbon Monoxide	1.150	0.0184	
Hydrocarbons	0.460	1.4700	
Oxides of Nitrogen	46.0	47.8000	26.6
Oxides of Sulfur	306.0	116.0000	0.027
Particulates	9.9	1.6000	1.020

[1] Assumes fly-ash control only.

[2] No pollution control equipment.



8—From reported incidences of illness and death, the effects of sulfur dioxide pollution on health can be summarized as a function of concentration and exposure time. In the midrange area, noticeable health effects have been reported; in the color area above this zone, deaths have been in excess of normal incidence; in the area immediately below the zone, health effects are suspected. The curve does not take into account the concentration of particulate matter, which is also a factor.

that the washing technique can be used for about 20 percent of the coal consumed by the utility industry and can reduce the sulfur content to approximately one percent. For fuel oil, the first commercial desulfurization plant is now in operation in Venezuela and will furnish 100,000 barrels per day to the United States. It is reported that this process reduces the sulfur content from 2.6 to 0.5 percent—a giant step in the right direction.

The process of SO_2 collection after the fuel is burned applies to both coal and residual oil fuels. Of the many collection processes under development, a few have reached the pilot-plant stage.

Only recently, one system, called the dolomite process, has been installed in two operating power plants. Its effectiveness has not been demonstrated to date, but it is designed to remove 82 percent of the sulfur and 99 percent of the particulate. Dolomite, a limestone, is injected into the combustion chamber in a powdered form, where it reacts with about 20 percent of the SO_2 and practically all of the SO_3. The gas then flows to a wet scrubber that contains an aqueous suspension of limestone or lime particles that removes more SO_2, as well as fly ash. However, because of the use of dolomite limestone, the resulting total solids collected in the wet scrubbing system increase by a factor of three over the fly-ash content of coal alone.

Since no use has been found for these solids, a waste-disposal problem has been substituted for an air pollution problem.

Other methods of removal of sulfur from flue gases are under active development. These include catalytic oxidation, alkalized alumina, and Reinluft processes, to name but a few. Some of these processes are designed to recover elemental sulfur, others sulfuric acid. More development is needed in technology and size extrapolation for these systems to become commercially feasible.

For power plant applications, there are no existing systems for the control or recovery of the oxides of nitrogen as such. The dolomite method, discussed for SO_2 removal, does in fact remove about 20 percent of the oxides of nitrogen. Most of the research and applications engineering for NO_x removal result from the industries that manufacture or commercially use nitric acid. Economic considerations have lead to systems that recover NO_x, principally NO_2, and produce more nitric acid. Catalytic and/or chemical treatment systems have been developed to destroy that portion of NO_2 that cannot be recovered.

Emission studies indicate that modifications in the combustion process, such as lower temperature combustion, are the best way to decrease the emission of NO_x (approximately 50 percent). With this being the case, significant progress can only be expected with the next generation of boiler designs.

In summary, effective methods exist for the control of particulate matter emission. The dolomite system for SO_2 control (and to some degree NO_x control) is being tested on operating power plants. Significant reductions in NO_x emissions will only come with new combustion processes. Presently, power plants are being built with higher stacks, depending on broader dispersal of the pollutants as the principal method of reducing regional concentration.

4—Discharge Heat

Modern steam turbine equipment provides the highest efficiency of all the heat machines in practical use today. Using high-temperature, high-pressure steam (1000-1100 degrees F, 1800-3500 psia), today's modern fossil-fueled steam electric plants can attain an overall thermal efficiency of 37 to 38 percent. Nuclear plants produce lower temperature steam in the range of 500 to 600 degrees F at pressures of 800 to 1000 psia, so that total plant efficiency is about 31 to 33 percent. But even the lower overall efficiency of the nuclear plant still compares favorably with that obtainable from gas turbines (20 percent) and automobile engines (less than 10 percent).

In all these systems, the heat energy that cannot be converted to electricity becomes waste heat and is discharged from the system. To set the scale on the heat rejection requirements for the last quarter of the century, in 1965 the total cooling water used by the electric utility industry equaled 128 billion gallons per day. By the year 2000, without supplemental means of discharging heat to the environment, the once-through cooling water requirements would be 1250 billion gallons of water per day. If 30 percent of the power-generation waste heat is discharged to sea-water systems, this leaves 875 billion gallons of water per day required for once-through cooling of inland power generating plants. Since the average daily runoff in the United States is only about 1200 billion gallons per day, 875 billion gallons represents a very significant portion of all the water available.

Viewed in perspective, it must be remembered that cooling water is only an interim heat sink. The ultimate heat sink for power generation is the atmosphere, and all heat rejected to the environment, whether directly to the water, land, or air (or indirectly through the use of the electric power in machines, lighting, etc.), eventually must be rejected to the atmosphere. Taking only the waste heat that, on projection, will be rejected to the atmosphere directly at the power plants by the year 2000 (55×10^{16} BTU) and assuming that all this heat is rejected by water evaporation only, the amount of water consumed would equal 12.5 billion gallons per day or only one percent of the total national runoff.

Federal Water Quality Criteria for Temperature

The U.S. Government has asserted that pollution control is a national goal, with better sewage treatment having priority. Since heat addition to a stream containing sewage may enhance the organic reactions, thermal pollution becomes a problem with which power utilities are closely identified.

Any quantitative evaluation of the impact of heat from power plants must include the quantity and types of impurities that exist in the body of water; the types, diversity and quality of the aquatic biota and their respective sensitivity to temperature in the spawning, hatching, larvae, fry, and adult stages of development; and the three-dimension extent and location of the heat-affected zone of mixing.

With the same concern for aquatic life, the National Technical Advisory Committee on Water Quality Criteria (via the Federal Water Pollution Control Administration) recommended the following parameters be followed in regulating the discharge of heat by anyone into the nation's streams and lakes:

1) During any month of the year, heat should not be added to a stream in excess of the amount that will raise the temperature of the water at the expected minimum daily flow for that month more than 5 degrees F. In lakes and reservoirs, the temperatures of the water near the surface should not be raised by more than 3 degrees F.

2) The normal daily and seasonal temperature variations present before the addition of the artificial heat should be maintained.

3) The recommended maximum temperatures of the streams or lakes should be restricted by tabulated maximums compatible with the well-being of given fish and other life common to the waterway.

4) In coastal and estuarine waters, the discharge of any heated waste should raise the maximum daily temperature, on a monthly mean basis, no more than 4 degrees F during fall, winter, and spring and no more than 1.5 degrees F during the summer months.

5) The rate of temperature change should not exceed one degree per hour except when due to natural phenomena.

6) Suggested temperatures (as in the fish well-being limits) are to prevail outside of established zones of mixing.

Further qualifications were made in regard to the extent of the zone of mixing. This extent had been found to relate directly to the requirements of the stream or body of water for maintaining free passage of migrating aquatic organisms. This includes, perforce, not only the migrants themselves, such as the fish, but also the biota on which they feed. The passage zone allowed for must be a continuous stretch bordered by the same bank for a considerable distance to allow for safe and adequate passage up and down the stream, reservoir, lake, or estuary for free-floating and drift organisms. This passage zone should normally contain 75 percent of the cross-sectional area and/or volume of flow in the streams and estuaries. Furthermore, where there are several mixing areas close together, they should all be on the same side so the passageway is continuous. Finally, mixing should be accomplished as quickly as possible through the use of devices designed to assure that the waste is mixed with the allocated dilution water in the smallest possible area. At the border of this area the water quality must meet the requirements for that given area.

The intent of the mixing-zone standard is clear. However, by Federal admission, it is the least definite because of variability of flow condition with time in any body of water.

While the Federal Water Quality Act permitted those states that would do so to establish their own water quality standards due to the tremendous range of conditions and general ambient temperatures across the nation, most states have established 68 degrees F as the maximum allowable temperature for streams with cold-water fisheries.

For warm-water fisheries, the maximum allowable temperatures are generally in the range of 83 to 93 degrees F.

Where several species of fish are present in a lake or river, thermal discharges can result in a species shift so that nothing but the so-called rough fish remain and the commercial value of fishing in that area suffers a severe setback, even though the total number of fish in the stream may increase as a result of the thermal pollution. Consequently, many of the State and Federal regulations either in existence or in process include a suggested thermal load maximum of five degrees over ambient temperature (three degrees over ambient temperature for trout or salmon spawning streams).

Here again, the complexity of the life forms in the aquatic community and their relative temperature sensitivities dictate the need for a comprehensive biomass survey to assess the effects of significant quantities of additional heat in the body of water.

Methods of Heat Dissipation

Five general methods of supplying cooling water to a power plant condenser are in use today:

Once-Through Fresh-Water Cooling—Fresh water is circulated from a natural lake or river through the condenser and back to the lake or river. It has been the normal method of obtaining cooling water in the power industry in the past, and it generally is the most economical method.

Cooling Ponds or Reservoirs—Fresh water is circulated through the condenser and returned to a cooling pond for subsequent rejection of its heat by radiation and convection before being recirculated to the condenser. This method is receiving renewed attention as an economical method for dissipating waste heat.

Salt-Water Cooling—Utilization of salt water taken directly from the ocean is another method that has been used by some plants for a number of years. It provides good condensing temperatures and good back pressures but generally has a higher cost than fresh-water cooling because of corrosion problems.

Evaporative Cooling Towers—When ample supplies of cooling water are not available, the use of evaporative or wet cooling towers is sometimes indicated. Most of the waste heat is dissipated to the atmosphere by evaporation of a small portion of the condenser cooling water flow. In recent times, the natural-draft hyperbolic type of cooling tower has received favorable attention for large generating plants. The mechanical draft type has been used for years, not only in power generation plants but also in process industries and air conditioning applications.

Nonevaporative Dry Type Cooling Tower—This operates on the principal of direct transfer of heat from a tubed radiator type of cooling tower to the air. The towers can be built either as natural-draft cooling towers or with induced draft.

The environmental effects of each of these methods must be assessed in its own circumstances, for each has its own unique impact upon the natural environment. For example, cooling ponds require hundreds of acres of land area. The various forms of cooling towers not only add heat and possibly water to the atmosphere but are physically large obtrusive structures, usually dwarfing the power plants that they serve.

Concern has been expressed at the possible climatic changes that addition of water vapor to the atmosphere by massive cooling towers might cause. With an average annual rainfall in the United States of 4300 billion gallons per day, only 0.03 percent of the moisture that is currently precipitated daily would be evaporated. And on a local basis, the current siting criteria for most nuclear plants, if applied to all plants using cooling towers to maintain certain exclusion distance provisions, would tend to ameliorate any local short-term micro-weather effects such as fog or icing on heavily populated areas. On an equal heat dissipation basis, of course, the use of cooling ponds, lakes, and even natural rivers and streams still represents the same approximate amount of water evaporated to the atmosphere.

Salt-water cooling towers may one day be required. At the present time, neither the design and operating technology nor the environmental effects have been developed. To prevent salt entrainment from the tower and subsequent environmental damage, such a tower would require a retention system for the small water droplets that normally drift out with the air flow. Other special considerations in thermo-, aero-, and hydrodynamics will have to be made during the course of development.

In any case, a more comprehensive environmental study is usually in order when cooling towers of any kind are contemplated.

Heat Release on a Planetary Scale

The greatest heat supply to the earth's surface is the sun's thermal radiation, which is some 100,000 times the electrical energy output from all power plants in operation in the world today. If there were no heat loss from the earth by radiation, the solar addition would result in an increase in the mean temperature of the surface of the earth of about 6 degrees F per year. In contrast, all the heat releases from power plants throughout the world during the period 1970 to 2000 could only raise the temperature of the earth's surface one degree F in 10,000 to 100,000 years.

While the heat released by man's power systems is miniscule compared with the heat received from the sun, a large portion of the energy made available by man's activities involves the consumption of fossil fuels. Two of the combustion products of those fuels, carbon dioxide and water, strongly affect the capability of the earth to radiate excess heat to outer space. Present conditions on the earth are the result of an equilibrium reached between the heat coming in from the sun and that which is being reradiated into black space by the surface and atmosphere of the earth.

The content of water in the atmosphere is relatively self-limiting through the action of precipitation. Carbon dioxide, however, is removed from the atmosphere by less precipitous methods, photosynthesis and mineralization. The relative rates of those reactions are such that the present-day activities of man, through the combustion of fossil fuels, roasting of limestone, and burning of vegetation for land clearing, have surpassed the natural abilities of the biosphere to remove CO_2 from the atmosphere. For example, more CO_2 will be released to the atmosphere in 1970 than was released by man in all of history up through 1900. As a result, the CO_2 content is gradually increasing with time. If all other factors affecting the earth's heat balance remained constant, this buildup of CO_2 in the atmosphere, by the year 2000, could have a far greater effect on the temperature of the biosphere than the direct heat additions from the power plants themselves. For example, should the CO_2 content of the atmosphere so much as double, the concomitant decrease in the earth's ability to radiate heat to outer space would result in an overall temperature rise of 4 to 8 degrees. The consequence would be truly awesome and would include the melting of a large portion of the polar ice caps, with a resulting increase in the sea level of 100 to 200 feet.

Like most real-life systems, however, the assumption that all other factors would remain constant while the CO_2 content increased is not consistant with established information.

The existence of high-altitude particulate matter from natural and man-made sources has a direct effect on the transmission of the sun's heat to the earth. These particles arise from volcanoes and smokestacks by thermal motion of the air particles. Jet planes produce particles directly in the stratosphere. Small particles in the atmosphere reflect solar radiation and directly increase the so-called albedo, or relative reflectance of the solar energy. Depending on the size range involved, the particles may also reflect back to the earth radiant energy arising from it, further complicating any analysis of the relative contribution of CO_2 and particulate matter to the heat balance of the earth.

Further effects induced by the particulate matter in the atmosphere arise from the natural tendency for water vapor to condense on fine dust particles and to form clouds. At present, 31 percent of the earth's surface is covered by low clouds at any one time. An increase in this percentage to 36 percent, brought about by the concomitant increase of both particles and water vapor, would drop the surface temperature of the earth about 5 or 6 degrees, which by itself would be nearly sufficient to bring a return of the ice ages.

In the recent geologic past, the ice ages have reoccurred in cycles of about 10,000 to 20,000 years. Considering the effect of the atmospheric contaminants on the reflection, absorption, and leakage of heat, it is conceivable that man might shorten the ice-age cycle from tens of thousands of years to centuries or perhaps even decades. Conversely, it is conceivable that planetary environmental engineers of the next century might control the quantities and locations of these contaminants to constructively adjust climate and weather regionally.

As long as man's additions of heat on the planet remain insignificant in comparison to the thermal energy from the sun, and cause no upset of the heat balance, we can reasonably assume that "spaceship earth" will remain inhabitable. This does not mean, however, that severe local stresses to the environment may not occur if heat is carelessly discharged in a manner solely convenient to industrial plant operators. It is evident that the present Federal Water Quality standards provide only gross guidelines in maintaining the aquatic environment. The environmentally concerned industry will determine, in advance, the probable impact of heat on the natural ecosystem and be prepared to consider alternative sites as well as the addition of environmental protection systems.

5—Summary

In the ecology of man, it is abundantly clear, even today, that our *total* environment has been significantly improved over the past 50 years. But some of the costs in the form of natural degradation are yet to be borne in the decades to come.

In this brief review of environmental effects of steam electric generating stations, their emissions and the resulting effects of those emissions on the local and global environments have been briefly discussed. While there is every reason to urge care and caution in the specific siting of new generating and transmission facilities, there is ample evidence that these new systems, required to meet the public demand for electricity, can be constructed and operated so as to provide minimal harmful impact upon the natural environment.

While improving the quality of our environment is an important objective endorsed by everyone, a leaderless, headlong stampede to purge the environment of all forms of pollution can succeed only in destroying the means for implementing the objectives sought. For example, no one will argue that radiation exposure to humans should not be kept as low as possible. In keeping with this objective, every effort is being made to reduce the radioactive effluents from PWR plants—even though they presently result in an exposure of only 0.002 mrem/year to the general public. To appreciate the insignificance of this minor perturbation above natural background, the public should be made aware of the many other radiation sources to which they are exposed in their daily lives (Table I).

Other man-made sources of radioactivity also merit examination. For example, the average exposure to the general population in this country from diagnostic X-ray examinations is approximately 50 mrem/year at the present time (although there are valid indications from experts in the field that new techniques and equipment can be applied to reduce this number by at least a factor of 10). Thus, when PWR plant radioactive emission is viewed in perspective, it is found to be the most carefully controlled of all the environmental hazards and can thereby provide a desirable solution for some of our other more serious environmental problems.

In our planning, we must conduct the necessary scientific investigations to understand the existing environmental conditions at a proposed plant site, and follow these investigations with an assessment of the probable impact of the proposed power system. Obtaining this quantitative information, using it wisely in our decision processes, and communicating both the information and the decisions adequately to the public will be a major new challenge in the 70's.

Westinghouse ENGINEER **May 1970**

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Relaying Analysis to Improve System Reliability

W. E. Feero
J. A. Juves

Rapid growth in size and capacity of any power system increases the complexity of the protective relaying problem and creates continually changing system conditions. Use of digital computer programs for relay coordination can facilitate the application and updating of the protective system.

Relays are installed on any power system to sense and, if necessary, isolate a local system disturbance before it spreads into an area-wide shutdown. Therefore, it is of fundamental importance that relay application and coordination be not only exacting but that it be made with consideration of its effect on all other relays in the protective system. Succinctly, relay schemes must be designed with a systems approach.

After-the-fact analyses of power system disturbances repeatedly reveal that the relaying operated just as it was designed to operate. Only on rare occasions were the settings based on incorrect information. Unfortunately, the outsider almost invariably looks to relaying as a cause for a major system disturbance. Because of the complexity and the magnitude of the relaying problem, it is sometimes difficult, if not impossible, for even the relay engineer to establish beyond doubt that the protective system did perform as it should.

The complexity of the problem can be alleviated by using a digital computer in the system analysis. Westinghouse has developed a set of computer programs that take into account the various fault and outage conditions that can occur. By using the computer's large memory to detail the rules and procedures required, the overall relaying of a system can be developed in a condensed and compacted form. The end result is a summary report, automatically created, that can be used for management presentation and yet provides complete technical details to support the results.

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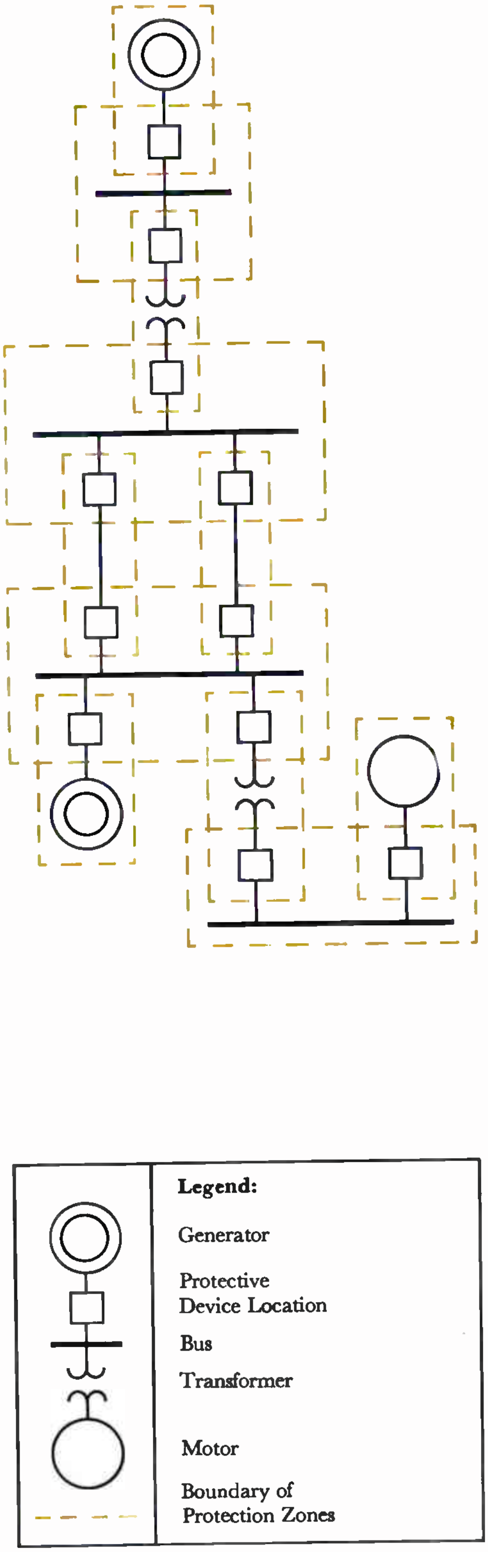


1—The interlocking of protection zones is indicated for an elementary power system.

Philosophy of Zone Protection

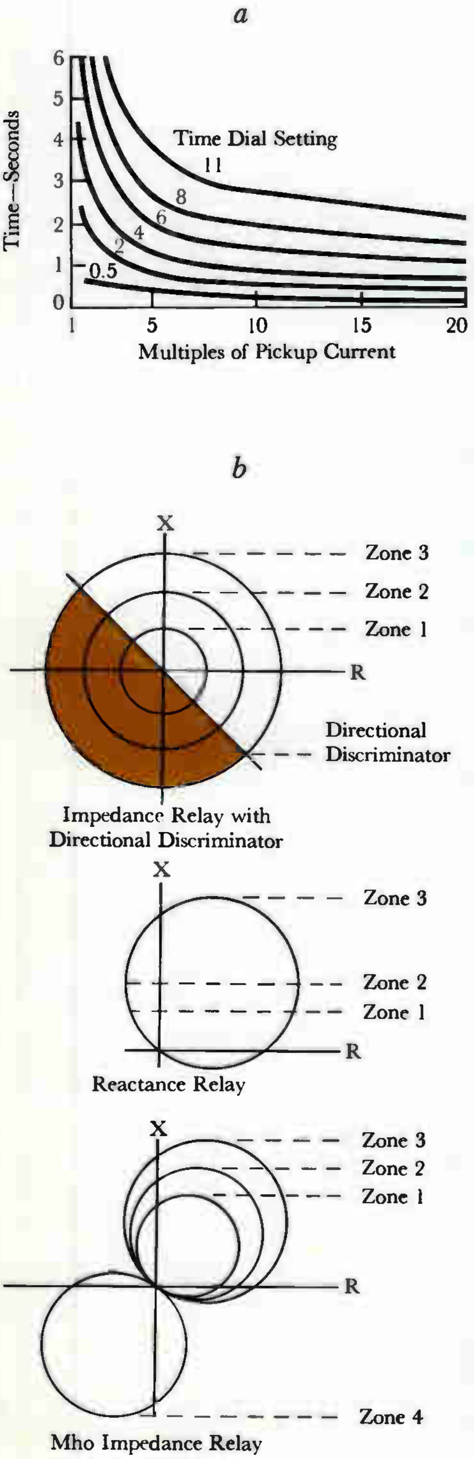
An elementary power system one-line diagram including generators, transformers, buses, lines, and motors is shown in Fig. 1. Protective device locations for fuses, reclosers, or breakers are present on each side of each piece of apparatus so that each protective device is involved in two protection zones.

A protection zone, the area around a piece of apparatus that can be separated from the rest of the system by protective devices, is shown by the encircling dashed lines. All protective devices involved in separating a protection zone from the system are just inside the zone.

In the converse sense, the protection area is the primary protection zone for each protective device on its boundaries. Thus, each protective device normally has two primary protection zones.

Generators, buses, transformers, and motors are very compact compared to the area covered by a power system. For this reason, standard practice has all protective devices within such a "compact" zone interlocked with each other (Fig. 1). The protective devices can readily determine when a fault is internal to the zone, in which case all devices on the zone boundaries clear instantly; for faults external to the zone, the boundary devices do not operate. Thus, overlapping zones provide each piece of apparatus with instantaneous fault protection.

Transmission lines differ from the other elements of a power system in that distances between line terminals may be as great as 250 miles. When there is communication between protective devices on zone boundaries (pilot relaying), system coordination is no problem. However, communication between line terminals may not be practical, either because of voltage levels or other system design considerations. In this case, the protective devices on the boundaries must be applied and set to coordinate with the remainder of the system (allow sufficient time for adjacent zone protective devices to operate for external faults). The protective devices must make decisions to trip or not to trip based entirely on voltage and current information available at the device location. Such



2—Protective devices usually employ one of two basic relay operating characteristics: (*a*) a time-overcurrent relay such as the moderately inverse characteristic shown, or (*b*) one of several forms of distance relays.

protective devices generally have two basic operating characteristics, current sensing and impedance sensing, as shown in Fig. 2a and 2b respectively. The application and setting of these devices cannot be satisfactorily determined without a thorough investigation of the total system under fault conditions.

Most protective devices also have a secondary function of providing back-up protection to adjacent protection zones. Back-up protection also must be accomplished by sensing the need for device operation on the basis of voltage and current information at the device location. The application and setting of back-up protective devices requires an even more exhaustive system analysis than does primary line protection.

System Representation

To demonstrate the computer approach to system relay coordination, the sample system represented in Fig. 3 will be used. Buses, lines, and protective device locations are numbered on this one-line diagram, and the per-unit values of the line impedances shown. This diagram depicts the topological arrangement for the phase relaying of the system. A similar diagram would have to be developed for ground relaying, since sections of the system become isolated by delta-wye transformers and have ground sources and zero-sequence line impedances which are quite different from the phase diagram.

Representation of a power system in this manner is quite conventional except for the protective device locations. The locations designated as 1, 2, 3, . . ., 30 on the diagram may represent fuses, reclosers, or breakers and their complement of relays. In accordance with electric utility and industrial practice, a location never represents a combination of the basic types of protective devices (fuses, reclosers, and relays). Locations representing circuit breakers may have impedance relays, overcurrent relays, and pilot-type relays at the one location.

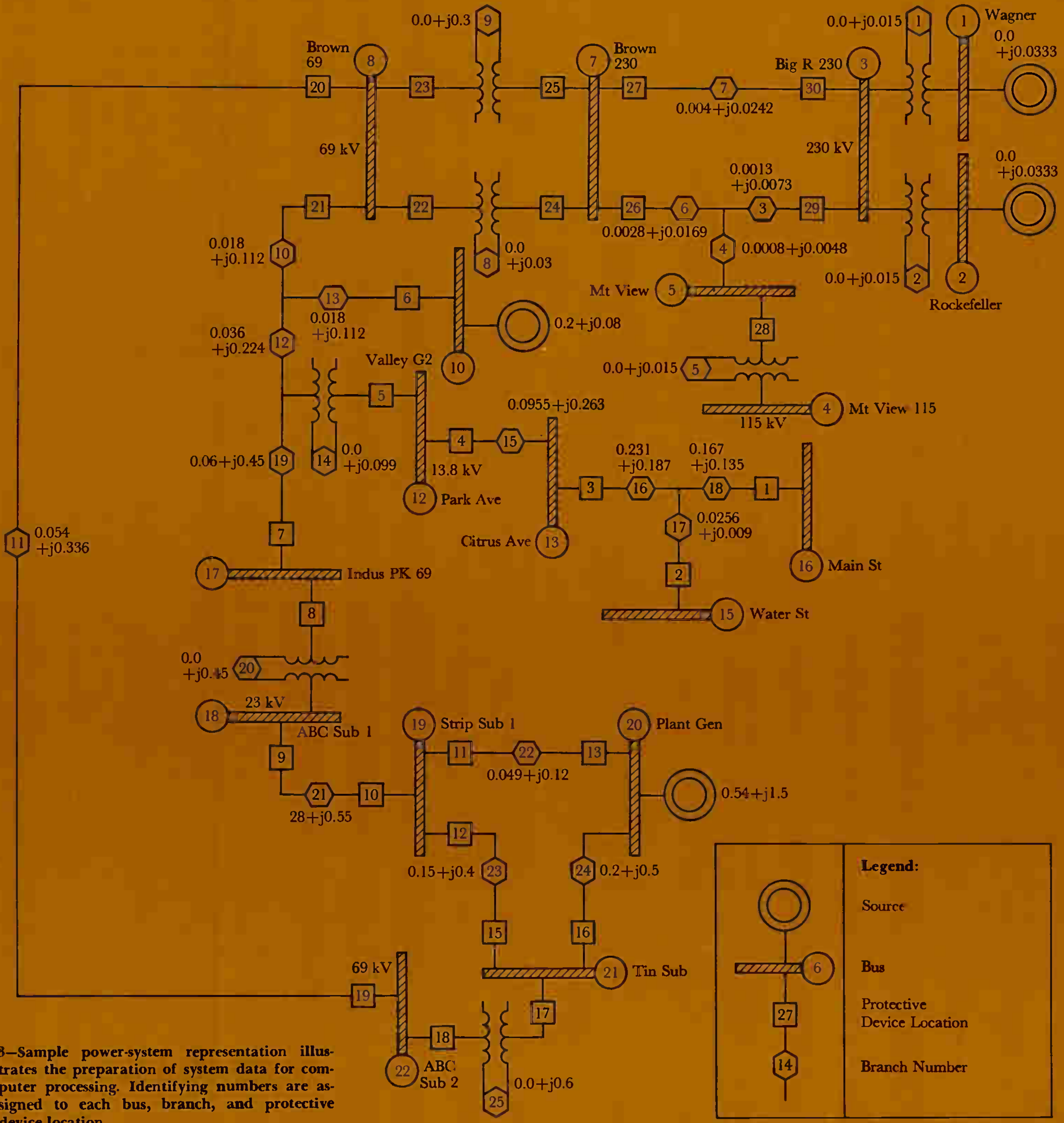
Protective device locations are shown at the effective *sensing point* of the device. For fuses and reclosers, this corresponds to the physical position of the device. In the case of relays where fault current information is supplied by current transformers, the electrical sensing point is assumed to be at the breaker location.

To automatically select and coordinate protective devices, it is fundamentally important to automatically calculate all fault current and voltage information required. The amount and type of fault data required can be most easily visualized by considering a small segment of a large power system (Fig. 4). The topology of the system in the shaded area is unknown but with the arrangement of buses, lines, and locations shown, this figure could represent a section of virtually any power system.

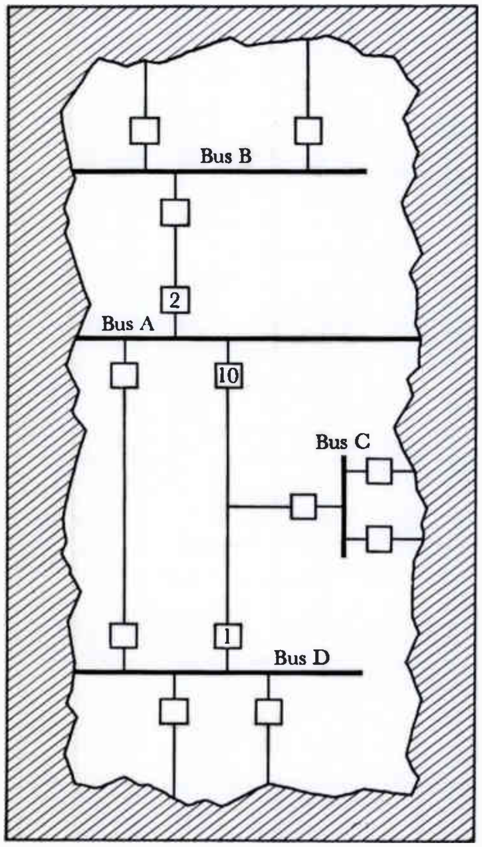
The maximum value of current through Location *1* is required for faults on Bus *D*. This value might be used to check for false tripping of an instantaneous relay at Location *1*. A simple bus fault produces a current in Location *1*, but if the line paralleling that of Location *1* is removed, a larger value of current flows in Location *1*. Similarly, if any of the lines radiating from Bus *D* are connected through the shaded areas to Buses *A* or *C*, the fault should be determined for each of those lines out of service. In general, to find the maximum value of current through a location for single line outage conditions, short-circuit calculations should be made with each line attached to the bus removed one at a time.

A similar evaluation for Location *10* would require the same fault conditions on Bus *A*. This fault information created by taking such faults on Bus *A* would allow further investigation of Location *1*, if voltage and currents are calculated for Location *1*. A fault on Bus *A* is at the remote end of Location *1*'s protection zone. This fault information along with that generated by faults on Bus *D* will provide further information needed to make the decision on what type of instantaneous coverage will be required (instantaneous overcurrent, impedance, or pilot protection).

A measure of the coordination requirements between Location *1* and Location *2* can also be had from this fault information on Bus *A*. Electrically, there is no difference between a fault on Bus *A* and a



3—Sample power-system representation illustrates the preparation of system data for computer processing. Identifying numbers are assigned to each bus, branch, and protective device location.



4—This single-line diagram shows a typical section of a large power sytem.

fault just on the line side of the terminals of Location *2*, except for the current through Location *2*. This current is computed as the total bus fault current less the contribution existing in Location *2* for the bus fault at *A*. This calculated fault represents a "close-in" fault. The removal of lines one at a time around Bus *A* provides restrictive coordination conditions for Location *1* coordinating with Location *2*. If major generation should exist at Bus *C*, it would be necessary to remove the line connected to Bus *C*. This condition requires an additional set of fault calculations where lines must be removed one at a time around buses one bus back in the system from the faulted bus. (This is discussed more completely under the section *Coordination Pairs.*)

This fault option can be utilized for faults on Bus *B*. Bus *B* is at the end of Location *2*'s primary protection zone. In many cases, it may be of extreme importance to evaluate the coordination between Location *1* and Location *2* for faults in the vicinity of Bus *B*. For this reason, voltages and currents should be available at buses two buses back in the system from the faulted bus. Such information would allow the appraisal of coordination between Location *1* and Location *2* for faults at the remote end of Location *2*'s protection zone.

In considering faults required for the coordination between Location *1* and Location *2* for faults at Bus *B*, one further condition must be considered. If Bus *D* should be connected to Bus *B* through the shaded area of the system by multiple paths, then the current in Location *1* would increase upon opening these connections. This can be accomplished by placing a fault on the Bus *B* end of the line of Location *2* with the line disconnected from Bus *B*. Such a fault is called a "line-end fault." This simulates the high-speed clearing of a device close to a fault and the associated redistribution of the fault current in the system.

The Westinghouse short-circuit program calculates all these conditions by inputing a simple code number with each of the buses that are to be faulted. This is one of the few automatic programs that actually make vector calculations of real and imaginary current and voltage flows in the system under fault conditions. Since most protective devices are vector sensitive, it is imperative that any application made uses vector quantities. Briefly, the philosophy of the Westinghouse program is to construct an impedance matrix and invert this matrix to allow the vector calculation of current and voltage. It is possible from this fundamental set of equations not only to calculate fault conditions at any bus in the system but also to calculate fault currents and voltages at any bus in the system with a varying assortment of lines removed.

The Westinghouse fault program automatically generates the following fault conditions:

1) Fault on the bus with all lines in the system;

2) Fault on the bus with one line at a time removed from the bus;

3) Line-end faults on each line connected to the bus with the breaker between the line terminal and the bus open;

4) Fault on a bus with lines removed one bus back in the system from the faulted bus.

All this data should be created for both maximum and minimum generation conditions. The fault conditions described should produce currents in lines around the faulted bus and around buses one and two buses back from the faulted bus. As indicated above, vector voltages should be produced at the faulted bus and one and two buses back in the system. (A bus is defined as a major or protected substation or point in the system; the junction of three terminal lines is not considered a bus.)

Although it is possible to conceive conditions more extreme than those listed for which data would be necessary to adequately coordinate devices in a system, it is, in general, not necessary once the logic of the relay program has been applied. However, it is possible to generate as many as five lines at a time out for a fault with the short-circuit program. This provides the flexibility to generate nearly any conceivable condition for which the system might have to operate. Once the short-circuit results as described for both maximum and minimum generation conditions have been calculated, they are stored in a convenient sequential order for later use in the selection and coordination of protective devices.

Coordination Pairs

On a system where all of the protective devices have been applied, it is necessary to determine settings for each of the devices so that they will operate with maximum speed to prevent damage to the apparatus and avoid system instability, and yet provide maximum selectivity so that only the faulted area will be isolated. To obtain such settings, it is necessary to obtain a relative positioning of each device in the system. This is best accomplished by developing a table of *coordination pairs* for each protective-device location.

A coordination pair consists of the protective device with a fault in its primary protection zone and the next adjacent protective device that can also sense the fault. The next adjacent device that can sense the fault is termed the back-up device because it must allow sufficient time for the primary device (the device with a fault in its protection zone) to clear the fault. The back-up device setting must be adjusted to meet this condition with sufficient margin for error.

To automatically develop coordination pairs, each protective device is investigated for back-up functions and a table of back-up/primary relationships listing the associated protective device numbers is tabulated. Only two pieces of system information are required to completely describe all possible coordination pairs for the system, and both items are available from system short-circuit data: (1) A knowledge of forward and reverse current flow through each protective device; (2) the directional characteristics of each protective device. By combining these two pieces of system data with topological tracing techniques, all possible coordination pairs can be developed and tabulated. Because fault data was used in the development of the coordination pairs, no trivial pairs are developed, i.e., overcurrent relays on radial lines backing up system relays. With these coordination pairs, it is now only necessary to decide what fault conditions are required to completely set the relays.

Current Pairs

To economically coordinate protective devices from such a massive amount of data, it is necessary to generate a table of currents producing the most severe coordination requirements. Although it is technically possible to coordinate all protective devices for every fault condition generated, it is not economically practical. Therefore, six fault conditions and corresponding current pairs for each coordination pair have been developed that allow the coordination of virtually all forms of protective devices. A current pair is defined as the current at the overreaching back-up device and the current at the overreached primary device for a given fault condition.

In the development of current-pair logic, it is assumed that the device to be coordinated (the overreaching device) need only coordinate with the next adjacent device (the overreached device) for faults within the overreached device's protection zone. Therefore, it is necessary only to evaluate currents and voltages at the overreached and overreaching devices for the maximum and minimum fault flows at the extremes and at points of discontinuities within the overreached relay's protection zone.

A simple radial system for which the currents in the overreached and overreaching device are the same is shown in Fig. 5. (Most situations are not this simple, and situations illustrating more complex current relationships are demonstrated in Fig. 6.) It is necessary to know the effects of a fault located at the end of the overreached device's *M* protection zone, i.e., on *M* location's far bus. This fault will be two buses away from the *I* device (the overreaching device).

To get the worst condition of coordination for a fault on *M* location's far bus, it is necessary to search all the solutions for faults on this bus to find one that produces the maximum current in the overreaching device. This current will produce the *fastest* operating time at the overreaching location and is thus a logical choice for developing a current pair (*CP1* in Fig. 5).

The minimum current at the overreached location for a fault at *M* location's far bus produces the slowest operating time of the overreached device while clearing faults in its own protection zone. Since this most often occurs for the minimum fault at *M*'s far bus, this minimum fault represents the condition for current pair *CP2*. The overreaching device should coordinate with (i.e., operate more slowly than) this slow operating time. To cover the effects of fault impedance, once this current is found, it is divided in half. This condition is the lower limit of currents for which coordination is required.

A third current pair relationship of extreme importance is that pair for which maximum current can flow in the overreaching location for a fault close in to the overreached location. This fault is just beyond the overreaching device's own protection zone. Since the fault is in the area, the overreaching device should operate as rapidly as possible and yet it must be slower than the overreached device. Such a fault creates the upper bound of currents for which coordination is required and is used to generate *CP3*.

To cover the point of discontinuity, where instantaneous tripping functions cease and timed overcurrent functions begin, it is desirable to create a current pair that effectively simulates a fault just beyond the instantaneous setting of the overreached location. When an instantaneous overcurrent trip device is present at the overreached location, a current one ampere less than the instantaneous trip setting is assumed in the overreached device. The current in the overreaching location is this current multiplied by the ratio of the first current pair developed. This yields *CP4*. The reason for using this ratio is that the end of the instantaneous trip range should be closest to the far bus. However, because of the extreme fault conditions generated, it is necessary to check that such a fault does not produce a current greater than that produced by the third current pair developed (which was the largest possible current flow).

Should this occur, the fourth current pair is eliminated because the third current pair (*CP3*) has covered this condition.

A fifth current pair (*CP5*) is developed to provide a set of points to assist in approaching optimal coordination. To insure that system conditions will not cause a cluster of current pairs in just two areas, this current pair is created as the average of the second and the fourth current pairs. (If the fourth current pair does not exist, then the average is based on the third and second current pairs.) A current pair created in this manner along with the others generates at least three distinct current pairs for comparing the relay curves of the overreached and overreaching devices. In the coordination process, this will allow optimizing the application of relays with varying inverse characteristics.

Finally, a sixth current pair (*CP6*) is developed for a fault at the far bus of the overreached location in the same position as that of *CP1* and *CP2*. However, this current pair is for the maximum ratio of current in the overreaching location to current in the overreached location, disregarding magnitudes of currents in either location. This current pair will normally be the same as the first current pair (*CP1*); however, under specific line-outage conditions of looped systems, it can be drastically different and can be the constraining current pair. For example, in the coordination of Location *15* over Location *11* of Fig. 3, *CP1* produces 1882 amperes in the overreaching device (Location *15*) and 3169 amperes in the overreached device (Location *11*). *CP6* produces 990 amperes in both devices. Both current-pair conditions only produced a coordination margin of 0.42 second. Had the overreaching relay been less inverse, *CP6* would have been the constraining condition.

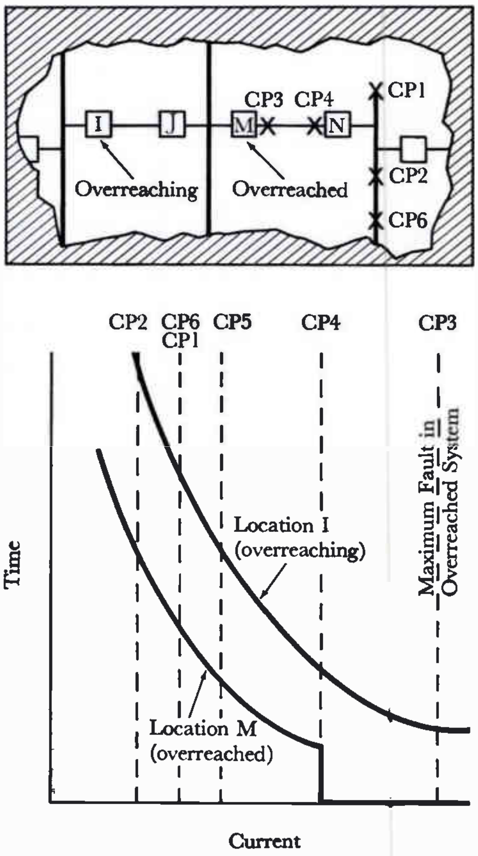
An interesting extension of the current pair concept occurs if Location *M* in Fig. 5 does not exist. Location *I* would be the overreaching location and Location *N* would be the overreached location. The first, second, and sixth current pairs would be developed exactly as described above with faults in the same positions. The third and fourth current pairs would not exist for this configuration because the faults would be between the devices. The fifth current pair would have to be expanded to handle this condition. Therefore, when the third and fourth current pairs do not exist, the average of the first and second current pairs is used to create the fifth current pair.

With these concepts applied to the relaying of the system shown in Fig. 3, the computer develops a coordination tabulation as illustrated in Fig. 6. This is just one page of the 17 pages required to tabulate the complete coordination of the entire system. The current pairs listed are current pairs 1 through 6 as discussed.

Note that the conditions of coordination between two protective devices are concisely defined. The pertinent information such as fault-current magnitudes, fault position in the system, and relay operating times are given. Should coordination be lacking between any of the devices, a comment "NOT COORDINATED" is printed in the right-hand margin. Thus, the relay engineer can rapidly review the entire relaying of his system for trouble spots. An example of the type of pinpointing diagnostics available from this printout is the comment "MAX TIME EXCEEDED" opposite *CP2* of Location *6* overreaching Location *22*. This comment indicates that the operating time of the primary or overreached relay is very slow. If possible, the relay engineer would take some special action to eliminate this condition.

Summary

In the limited space of this article, it is impossible to cover the many and varied relay schemes that require coordination. What has been attempted is to point out that by generalizing all systems it is possible to automatically create all the fault data required. Then, a set of basic conditions have been constructed that when used with this data, encompass the constraining coordination conditions of any relaying scheme. Since the elements of this approach are fault magnitude, fault position, and operating time, any type of relay (overcurrent, time-distance, impedance, or combinations) can be coordinated in a consistent and concise manner.



5—(*Above*) Coordination curve for determining current pair relationships is developed by superimposing operating characteristics of the overreaching and overreached protective devices. Operating times are determined for current pairs that produce the most severe coordination requirements.

6—(*Right*) Excerpt from a computer-generated table of current pairs shows three coordination pairs for the power system represented in Fig. 3. The printout contains such pertinent information as fault-current magnitudes, fault position, and relay operating time.

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                                       TABLE OF CURRENT PAIRS

              ************  DEFINITION OF ABBREVIATIONS USED IN THE FOLLOWING PRINT OUT  ************

             AMPS = AMPERES

             FBN = THE FAULT BUS NUMBER THAT PRODUCED THIS CURRENT PAIR

             MT = MULTIPLE OF TAP FOR RELAYS, FOR FUSES AND RECLOSERS IT IS MEANINGLESS AND IS SET TO ZERO

             OT = OPERATING TIME OF THE DEVICE


  OVERREACHING LOCATION,     4                 OVERREACHED LOCATION, NO.    3
   RELAY     CO-  7                               RELAY     CO-  6

  AMPS    4441 (FBN 15) MT  7.40, OT     .48   AMPS  4441 (FBN 15) MT 12.34, OT    .23
  AMPS    1867 (FBN 16) MT  3.11, OT     .79   AMPS  1867 (FBN 16) MT  5.19, OT    .25
  AMPS    6270 (FBN 13) MT 10.45, OT     .42   AMPS  6270 (FBN 13) MT  0.00, OT   0.00
  AMPS    5328 (FBN 15) MT  8.88, OT     .44   AMPS  5328 (FBN 15) MT  0.00, OT   0.00
  AMPS    3598 (FBN  0) MT  6.00, OT     .53   AMPS  3598 (FBN  0) MT  9.99, OT    .23
  AMPS    4441 (FBN 15) MT  7.40, OT     .48   AMPS  4441 (FBN 15) MT 12.34, OT    .23

  OVERREACHING LOCATION,     5                 OVERREACHED LOCATION, NO.    4
   RELAY     CO-  7                               RELAY     CO-  7

  AMPS    6270 (FBN 13) MT 10.45, OT     .69   AMPS  6270 (FBN 13) MT 10.45, OT    .42
  AMPS    3135 (FBN 13) MT  5.22, OT     .94   AMPS  3135 (FBN 13) MT  5.22, OT    .56
  AMPS   10731 (FBN 12) MT 17.88, OT     .57   AMPS 10731 (FBN 12) MT  0.00, OT   0.00
  AMPS    7522 (FBN 13) MT 12.54, OT     .65   AMPS  7522 (FBN 13) MT  0.00, OT   0.00
  AMPS    5329 (FBN  0) MT  8.88, OT     .74   AMPS  5329 (FBN  0) MT  8.88, OT    .44
  AMPS    6270 (FBN 13) MT 10.45, OT     .69   AMPS  6270 (FBN 13) MT 10.45, OT    .42

  OVERREACHING LOCATION,     6                 OVERREACHED LOCATION, NO.   22
   RELAY    KD+CR 11                              RELAY    KD+CR 11

  AMPS    2082 (FBN  7) MT  3.47, OT    3.01   AMPS  1184 (FBN  7) MT  2.96, OT   2.34
  AMPS    1024 (FBN  7) MT  1.71, OT  777.77   AMPS   553 (FBN  7) MT  1.38, OT 777.77  MAX. TIME EXCEEDED
  AMPS    2174 (FBN  8) MT  3.62, OT    2.75   AMPS 10268 (FBN  8) MT  0.00, OT   0.00
  AMPS       0 (FBN  7) MT  0.00, OT  999.99   AMPS     0 (FBN  7) MT  0.00, OT 999.99
  AMPS    1599 (FBN  0) MT  2.67, OT    5.48   AMPS   910 (FBN  0) MT  2.27, OT   4.39
  AMPS    2049 (FBN  7) MT  3.41, OT    3.12   AMPS  1105 (FBN  7) MT  2.76, OT   2.75
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Protective Devices and Terms Referred To:

CO-6	A Westinghouse definite time, nondirectional, overcurrent relay.
CO-7	A Westinghouse moderately inverse time, nondirectional, overcurrent relay.
CR-11	A Westinghouse extremely inverse time, directional, overcurrent relay.
KD	A Westinghouse impedance relay.
999.99	Indicates that the protective device will not operate for the fault condition.
777.77	Indicates that the protective device will operate but not in any accurately predictable manner.

Selecting a Minicomputer for Process Control

G. L. Kilgore

All minicomputers can be programmed to perform a variety of control functions without the many special control devices otherwise required. However, not all of them are as capable and flexible as the Prodac 2000.

For a number of years, the choice between computer control and hard-wired logic control has been relatively easy. For simple control functions in a stable process, wired logic systems have been the economical choice because of their modest initial cost. But where the system has been required to control many different functions, and where there was a high probability of a need for change or expansion, the computer has proved more economical because of the ease with which it can be reprogrammed to perform additional functions with little or no additional hardware.

Now, however, the advent of minicomputers has introduced new criteria for selection of a control approach. (The term "minicomputer" is used here to mean a small general-purpose computer that can be purchased for less than $25,000.)

The price per computation with these new machines is low enough to make them competitive for many applications that were previously considered uneconomical for any type of computer control (such as machine-tool control, data terminals, and automated production facilities). Moreover, their flexibility permits the minicomputers to compete with large computers in many situations where multiple units can be used.

All digital computers have a number of characteristics in common. All have a memory, an arithmetic unit, and logic to manipulate the data among the internal data registers (which hold binary data for storage or manipulation). However, no two computers manipulate data in exactly the same way. Obvious variations include core cycle time, number of instructions, and number of flip-flop registers, but there are also more subtle differences. Among them are the capability of the instruction repertoire, the methods of addressing memory, the input/output structure, and the software support available; all have a significant effect on the computer's performance in a particular application.

In selecting a small computer from the variety of models available, price should be only one of many factors considered. Choosing a computer is essentially no different from choosing conventional control components in that it requires an analysis of the manufacturer's application capability and of the equipment in the light of specific requirements. Some important factors to consider are discussed in this article.

Application Experience

Minicomputers are designed to criteria established by the manufacturer. It is he who chooses the word size, speed, instruction repertoire, memory size, and other characteristics that determine how his machine functions in any situation. One basis for evaluating the manufacturer's capability in control applications is his experience with control

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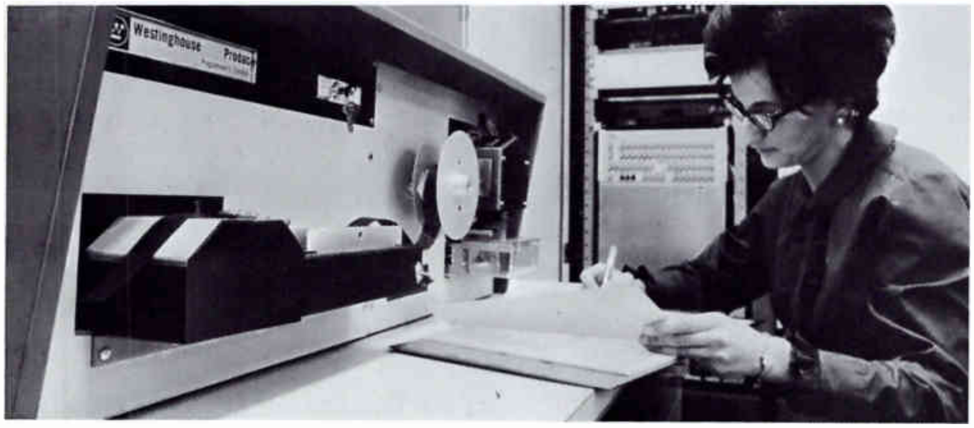


Photo—Programmer's console for the Prodac 2000 computer system gives an operator access to a communication program that is part of the system's Fundamental Executive program. The communication program simplifies numerical conversion of data, performs arithmetic calculations, controls the running of other programs, and helps in program debugging. Like the rest of the system, it is modular so that its scope can be restricted to the needs of the particular application to save both money and memory space.

1—(***Right***) Central processing unit (CPU) of the Prodac 2000 minicomputer consists essentially of four large printed circuit cards with a general function assigned to each card, although additional memory cards can be added if more core memory is needed. Fast-access memory is located on the second card; that card is shown linked to the first one because the two are functionally inseparable.

problems. If he is oriented toward data processing, his machines probably are structured for data handling applications and may be difficult to apply successfully to process control. If the manufacturer is experienced in industrial process control, his machines probably reflect that experience.

The Westinghouse minicomputer—the Prodac 2000—is the direct result of years of experience in process control systems for steel mills, furnaces, utility power plant and dispatch systems, machine tools, automated warehouses, and many other applications. Both the structure of the hardware and the techniques of programming are tailored specifically to known problems in those fields.

Applications the Prodac 2000 system is suited for include rolling mill control, arc furnace demand control, BOF control, continuous casting control, process simulation, material flow control, automatic warehouse operation, machine tool control, product testing, pipeline terminal operation, and electric power system control, logging, monitoring, alarming, and dispatching.

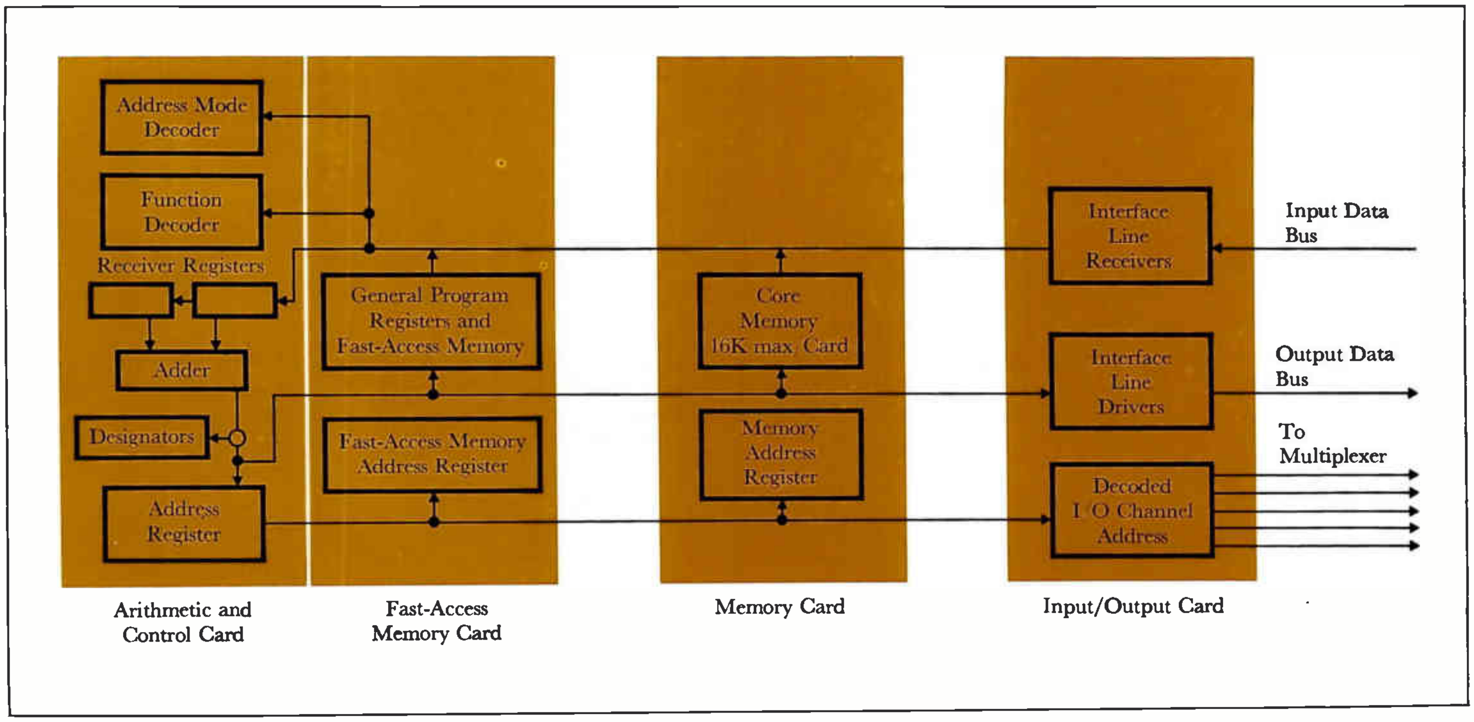
Central Processing Unit

In the control of any process equipment—whether it be a paper mill digester, a machine tool axis, a power plant, or a neon sign—the decisions and calculations provided to carry out the control are called the algorithm. The control equipment must be able to execute the control algorithm successfully to be in control of the process.

The arithmetic or logical manipulations that the control algorithm requires dictate the capabilities required of the basic computer (which is known as the central processing unit, or CPU). An example is the accuracy of numbers. The arithmetic calculations needed to determine what control action is required must be represented in the computer's memory in binary notation, and the greater the number of binary digits (bits) there are in the memory "word," the greater the accuracy of the number that can be represented.

The range of each variable and the accuracy required determine the number of bits needed to contain the number. Two 8-bit memory words, for example, are needed to contain the equivalent of one 16-bit word, so a 16-bit 4000-word memory can hold twice as many 16-bit numbers as an 8-bit 4000-word memory. A binary number contained in 16 bits can be accurately represented over a range of +32,768 to −32,768 to the nearest unit. For greater accuracy, two words of memory can be considered a single value called a "double precision" number.

Not all minicomputers have 16-bit core words and double precision add and subtract instructions. The ones that haven't can provide the necessary accuracy by subroutines, but those are much slower than the machine instructions. The Prodac 2000 computer is a full 16-bit parallel machine with double precision add and subtract instructions to permit direct arithmetic operation on 32-bit numbers. Also, both multiply and divide instructions are standard in the Prodac 2000 computer; they are not available in many other minicomputers, especially those of smaller word size. Again, the value is in time saved by not having to use a subroutine to execute the operations.



Another difference among minicomputers is in the power of the "scratch-pad" memory, that is, the extra flip-flop registers outside the main body of core memory. In the Prodac 2000 computer, those extra registers contain the general program registers (Fig. 1). Execution of instructions to or from the flip-flop registers is faster than from magnetic core memory, so much less time is required to operate repetitively on the same numbers. Some small computers are limited to using those registers for only certain instructions, and not all instructions address any location in memory. Several instructions then may be required to load the scratch-pad memory before the computational instruction can be executed. This costs time during program execution that the prospective buyer may not expect if he looks only at the time required to execute a multiply instruction.

The Prodac 2000 computer has fast-access memory as the first 16 core locations, and it also has the capability to operate directly on any location in core. Those two features combine the speed of the flip-flop registers and the addressing capability to operate directly on any location, either "scratch-pad" or main core. The ability to operate on any location is provided by the many modes of addressing available: absolute, relative, pre-indexed direct, pre-indexed indirect, and post-indexed indirect.

Absolute addressing allows operation on any of the first 256 locations by an instruction located anywhere in core memory. Relative addressing permits operation on any location within 127 positions before or after the location of the instruction being executed. Pre-indexed direct addressing permits operation on any location in memory; it is accomplished by modifying the absolute address by the contents of either of two index registers available.

The two indirect addressing modes permit operation on any location in core by using another location to hold the address of the ultimate destination. Pre-indexing modifies the address of the location where the address of the ultimate destination is found. Post-indexing modifies the address of the ultimate location.

This unusually large number of addressing modes permits the use of a high-level programming language without the cost in program execution time that frequently accompanies use of such a language. This factor, plus the reduction in running time made possible by the fast-access memory, substantially decreases the time required to execute complex control algorithms.

The Prodac 2000 CPU is constructed as four large printed circuit cards, each 16 x 28 inches (Fig. 2). A function is allocated to each card. One is the arithmetic and control card, one the maintenance panel and fast-access memory, one is capable of handling 16,000 words of core memory, and one handles input/output. Additional memory cards can be added for extra memory up to 65,000 words.

Interface with the Process

The computer package that is purchased by a user may be a CPU only, or it may include all the hardware required to wire it up to plant contacts. In any case, the main frame must somehow be connected to the equipment it is to control.

The signals available at the surface of the main frame are only those from data lines, address lines, and traffic control pulse lines (which indicate when data is available on the data lines). They are at the logic energy level and must be decoded, amplified, and isolated before they can be connected to power-level actuation equipment (usually 100-volt) in a plant environment. The logic that decodes the address data and switches it to and from the proper devices at the proper time is called the I/O (input/output) interface.

If the user buys interface equipment such as relay driver output circuits and dry-contact input circuits from the computer manufacturer, he must make certain that the signal voltage power levels are compatible with the equipment to be connected. Most manufacturers offer dry-contact digital interface equipment (100 voltamperes maximum) that plugs into their computers. The capacity of the contacts and the voltage levels supplied vary with the manufacturer.

Analog signal multiplexing and conversion equipment is also usually available for input from sensing elements, and the speeds and signal levels of such equipment vary greatly between vendors. Peripheral devices such as line printers, tape readers and punches, card readers and punches, and disc packs are also available with interface packages for most computers.

All of these devices and the interface equipment required are available with the Prodac 2000 computer. Experience with nearly 350 complete computer systems supplied to more than 200 customers to date has proved the design of current Westinghouse interface equipment to be highly reliable and of high enough power to interface with almost any electrical sensor, relay, or switch in common use.

When the user buys the manufacturer's I/O equipment, he should also acquire the executive program (also called monitor program). It provides most of the basic programs needed for I/O operations and gives the user's programmers easy access to all the I/O equipment purchased. Diagnostic programs are also provided for the I/O devices.

The Fundamental Executive program is the heart of the programming structure for the Prodac 2000 computer system. Among its advanced features are instructions to provide for multiple storing or loading of the general program registers; they are referred to as macro-instructions because they perform, in a single instruction, functions that would otherwise require seven individual instructions.

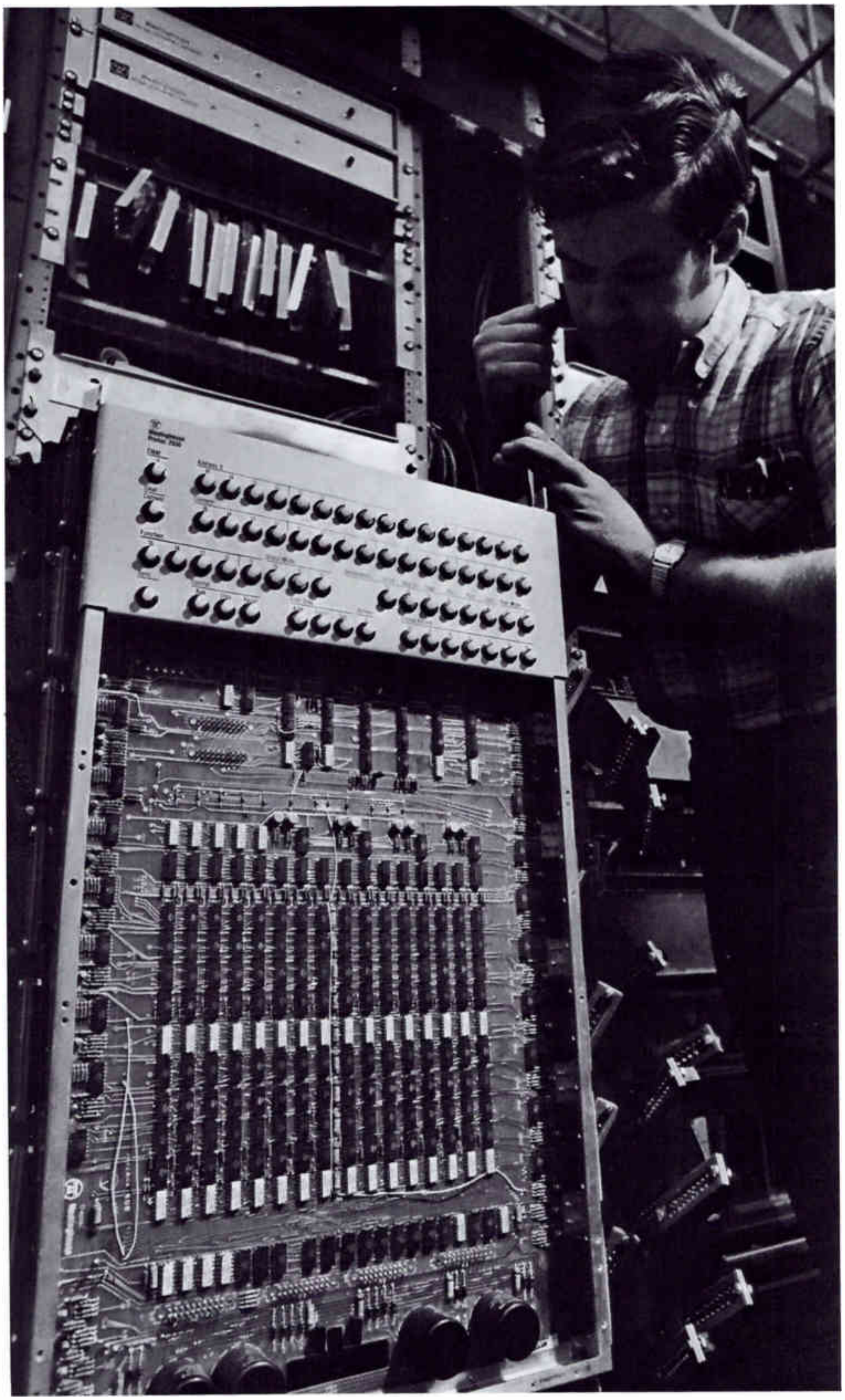
"Handler" programs are modules that can be added to the Fundamental Executive for all standard I/O devices, including contact outputs, analog and digital inputs, paper tape readers and punches, card readers, teletype units, line printers, and mass memory devices (Fig. 3). A handler program responds to the control signals from, and generates control to, a particular device. The programmer then can leave such details to the handler program and concentrate on the messages to be transmitted. As more devices are plugged in, more handlers are added to the Fundamental Executive to eliminate the need for direct reference to the devices.

A user who builds his own I/O interface has to build equipment that is electrically and logically compatible with the computer. Some machines require every input or output operation to pass the data to or from the accumulator register. Others have direct memory access capability. Some machines put data into memory between instructions, some between instruction subsequences. Each peripheral device available has its own speed requirements; therefore, the user's choice of devices to be used in his system will dictate the best type of interface for him.

All three methods of data transfer are available in the Prodac 2000 computer. Some data transfer channels pass all data through the accumulator register. Some can insert data into any memory location between instructions of a running program. By the addition of a cycle steal card to the basic configuration, data can be inserted into consecutive locations in memory between instruction subsequences during the execution of any instruction.

Data transfer within the computer is asynchronous; that is, instruction times depend on the speed of the memory printed-circuit card or the I/O card. Therefore, a machine can be speeded up if necessary, even after it has been in operation, by replacing the original memory card or I/O card with a unit designed for faster operation. The functionally separate cards provide a clean break between the I/O data bus and the memory data bus, permitting the I/O structure to be relatively independent.

In general, the user should undertake interface design only if repeat volume on similar systems justifies the development cost or if the needs of the application cannot be satisfied by the manufacturer's catalog of equipment. The development is costly and difficult.



2—The printed circuit cards of the CPU are mounted, one behind another, in a rack that slides out for easy access. Cards are connected by ribbon cable and plug connectors. Those two construction features make it easy to test cards and, if necessary, replace them.

Support Software

Computer manufacturers usually can supply support programs that reduce the effort required to create and test the control programs (which are those that have to be written by or for the system user to control his process). The support programs are written in a computer language that makes the computer aid the programmer by caring for details.

Different language levels are available: the higher the level, the easier (and therefore the less expensive) it is to program. Higher-level languages, however, are generally less efficient in use of memory than are the lower-level languages. The economic tradeoff lies between the cost of core memory and the cost of the programmer's time.

For example, if plans call for building several hundred identically programmed systems, it might be possible to reduce the cost of core memory for each system by using one of a class of lower-level languages called assemblers. The increased programming cost would be spread over the large number of systems.

Westinghouse has developed an especially capable assembler language. It takes full advantage of the powerful addressing capability of the Prodac 2000 computer by use of directives that automatically invoke the special addressing. For users who have a large data-processing computer, there is a version of the assembler that can be run on any FORTRAN-compatible system. Moreover, a simulator program has been written in FORTRAN for use in testing, on a data-processing machine, programs written for the Prodac 2000.

If, instead of many identically programmed systems, one unique computer system is needed, programming costs can be reduced (at the expense of additional memory requirement) by use of higher-level programming languages. FORTRAN has proved itself to be a good high-level language for process control because it is easy to learn and basic enough to be fairly efficient. However, there are nearly as many versions of FORTRAN as there are computers on the market. The American Standards Association has defined two levels of the language: Basic FORTRAN is the lowest level and is the one provided for most minicomputers; ASA FORTRAN is a higher-level language, equivalent to FORTRAN IV.

For the Prodac 2000 computer, Westinghouse offers an augmented ASA FORTRAN. It is compatible with, but even more powerful than, ASA FORTRAN, and it increases the computer's ability to deal with real-time situations. To accommodate the ASA FORTRAN programs, a complete set of subroutines is provided as part of the Fundamental Executive program.

This total package of FORTRAN support programs, I/O handlers, and Fundamental Executive program allows all programming effort to be directed to the control algorithm. There is no need to write programs to operate the equipment properly, to execute arithmetic operations, or for debugging aides.

Availability On Line

Availability is the sum of reliability and maintainability. Packaging, circuitry, and logic modules vary among minicomputers just as much as the design does. Besides looking at mean time between failures, the potential user should consider how easily problems can be diagnosed, where spare parts are located, and how fast the computer can be put back on line. The answers to those questions have as much effect on availability as the computer's reliability.

The control system builder and the end user have the greatest effect on availability. The environment in which the computer operates, for example, helps determine its life. Although the Prodac 2000 is a "blue-collar" computer that is expected to work in factory environments, its life at 120 degrees F is substantially shorter than at 70 degrees F. Similarly, operation is practically continuous in an electrically isolated chamber compared with operation next to a Van de Graff generator. And maintenance is much faster if a full complement of spare parts is on hand than it is if no parts are on hand.

However, there are some basic computer structural considerations that increase reliability and ease of maintenance. The Prodac 2000 computer's modular large-card construction provides for quick isolation of faults, and cards are easy to replace. Testing of cards is easy because they can be plugged into any slot and can be operated off-line; a suspect card works just as well in the front slot of the rack as in the rear, so it can be moved there for easy access in testing.

Use of the large printed-circuit cards also made it possible to connect them by ribbon cable and plug connectors that mate directly onto the cards. This construction has eliminated the less reliable wire-wrapped terminations found in computers with back-panel wiring in the CPU. Anticipated mean time between failures is one year (8700 hours).

Operating temperature range is from 0 to 55 degrees C (32 to 131 degrees F), and input line voltage tolerance is ±10 percent. The contact input interface equipment is filtered and isolated.

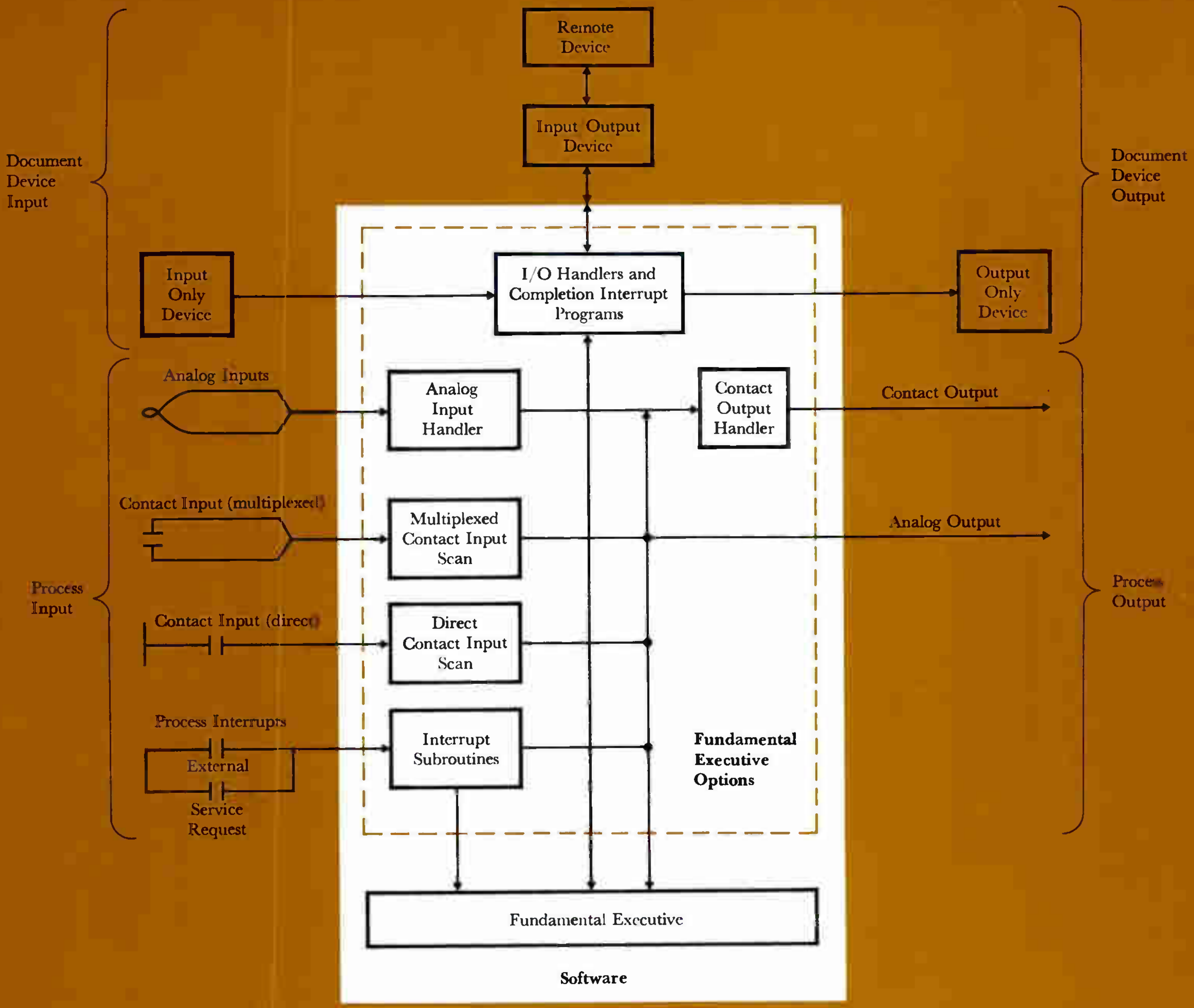
Descriptive Information

Almost as important as the computer design itself is availability of information about the design. A computer cannot control the parameters until it is connected to the process, and, unless the user has sufficient knowledge of the computer, he can spend hundreds of hours just learning how the connecting interface could be built.

The manufacturer is the only source of help at this point, so he should be one who can train the people involved in the project and provide information. Westinghouse provides schools, books, drawings, and people to aid at any level of effort from design of CPU circuit cards to full system design responsibility.

Conclusion

The proper starting place in selecting a control computer is a thorough knowledge of the application, and the only goal is determining the unit that most capably handles the control algorithm at minimum overall cost. The route to follow between those two points is best found by pooling the user's experience and the computer manufacturer's experience.



3—Relationships between a controlled process, the Prodac 2000 computer system, and the system's software are illustrated in this simplified diagram. The Fundamental Executive program is the heart of the programming structure; to it can be added various optional programs, such as handlers, to fit the system to the process that is being controlled.

Technology in Progress

Submarine Rescue Vessel Can Dive to 5000 Feet

The first deep-diving rescue submarine has begun tests and diving trials before going into service with the U. S. Navy. Developed by Lockheed Missiles & Space Company, the Deep Submergence Rescue Vehicle (DSRV-1) is the primary element in a system that can respond to a distress call anywhere in the world and rescue the survivors of sunken submarines in depths to 5000 feet. For quick response to a submarine disaster, the DSRV with its supporting system can be airlifted by three C-141 jet transports, as it was in its transfer from northern California to San Diego for launching. (See photograph, inside front cover.)

An integrated control and display (ICAD) system developed by Massachusetts Institute of Technology provides DSRV operators with data from sensors, including sonars and TV cameras, to enable them to perform the precise task of sealing their vessel's bell-shaped transfer skirt over a stranded submarine's escape hatch. Vertical and horizontal thrusters enable the operators to hold their craft in position over a stricken vessel despite currents in the water. The thrusters for propulsion and maneuvering, along with their power-supply and control equipment, were designed and built by the Westinghouse Aerospace Electrical Division.* By pumping mercury between tanks, the DSRV operators can roll and pitch their craft to match the angle (up to 45 degrees) at which the downed submarine lies on the ocean floor.

The DSRV has a free-flooding outer hull, made of glass-reinforced plastic, that surrounds an inner pressure hull formed by three connecting steel spheres. It is 50 feet long.

In a typical rescue mission, the DSRV and its support equipment will be flown to a port near the disabled submarine while a nuclear "mother" submarine modified to carry the DSRV is directed to the same port at high speed. There the DSRV and some support equipment are loaded on the mother submarine and carried to the rescue site. Near the disabled submarine, the DSRV leaves the mother submarine, descends to the disabled submarine, and mates with the forward or after rescue hatch. It takes aboard 24 survivors and carries them to the mother submarine, making as many return trips as necessary.

Use of a mother submarine permits rescue regardless of surface weather or ice conditions. In addition, the Navy's ASR-21 series of submarine rescue ships can serve as surface support ships for the DSRV.

Largest Railroad Car Delivers Utility Generators

A new and bigger version of the world's largest railroad car makes it possible to deliver larger generators for electric-utility plants. The car is 177 feet long when loaded, has a capacity of 1,200,000 pounds, and travels on 44 wheels. It takes the "world's largest" title from a similar car, two years old, that is 159 feet long when loaded and has a capacity of 1,046,000 pounds. Both are used to transport generators from the Westinghouse Large Rotating Apparatus Division to the sites of new electric power plants.

The cars are built in two sections. With front and back halves separated, the generator to be shipped is suspended between the sections to become an integral part of the car; when the generator reaches its destination and is unloaded, the two halves of the car are hooked together again for the return trip. A built-in hydraulic system can move the generator as much as 12 inches vertically and 14 inches horizontally to get past obstructions along a railroad. Such features permit much larger generators to be shipped by rail than would be possible with flatcars.

Like its predecessor, the new car was built by McDowell-Wellman Engineering Company, Cleveland, Ohio. The first shipment with it was a 760,000-kW generator sent to the Turkey Point nuclear unit being built near Florida City by Florida Power & Light Company. The rail car carried the generator as far as the Westinghouse plant in Tampa, and there the generator was transferred to an ocean barge for the rest of the trip.

Plutonium Fuel Assemblies to Be Demonstrated

Fuel assemblies containing plutonium soon will be in use at the San Onofre Nuclear Generating Station at San Clemente, California. Edison Electric Institute and Westinghouse are cosponsoring the study, along with the joint owners of the San Onofre station—Southern California Edison Company and San Diego Gas and Electric Company. The United States Atomic Energy Commission also is expected to participate by leasing the plutonium fuel at a reduced cost.

The broad purpose of the program is to study the economic use of plutonium in large pressurized-water reactors. A significant amount of plutonium will be produced in the next few years from operation of light-water reactors in the

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*Robert C. Fear, Robert R. Madson, and Joseph M. Urish, "AC Power Provides Flexible Maneuvering for Deep-Submergence Rescue Vehicle," *Westinghouse ENGINEER*, March 1969, pp. 41-45.

United States. While authorities agree plutonium will be best utilized as fuel in fast breeder reactors, such reactors are still under development and will not require plutonium in large quantities until the late 1970's or early 1980's. Thus, electric utilities must either stockpile the plutonium recovered from spent fuels, which would increase the cost of energy, or burn it in today's light-water reactors until the fast breeder reactor has been developed.

Specific technical objectives of the program include the design and fabrication of demonstration plutonium fuel assemblies; licensing, operation, and evaluation of the demonstration assemblies in a central-station power plant; and preparation of general design data for recycling plutonium routinely in large pressurized-water reactors.

Fabrication of 720 plutonium-bearing fuel rods is under way at the Westinghouse plutonium fuels development laboratory. The rods, containing a mixed oxide of plutonium and uranium, will become part of the fuel assemblies to be used for the August, 1970, refueling of the San Onofre station.

The plutonium fuel assemblies will be part of the reactor's core for approximately four years. During that time, their performance will be monitored and selected fuel rods will be removed periodically for examination and testing.

Environmental Management School Is Established

A school for environmental management has been formed at Fort Collins, Colorado, to train personnel from electric utility companies in the legal and technological aspects of the subject. The school will be operated by the Westinghouse Environmental Systems Department in cooperation with Colorado State University, with the first four-week course to be held in June. That course will feature recognized authorities in such fields as ecology, marine sciences, public health, meteorology, and environmental law, and it will include field trips, seminars, and laboratory work.

The Environmental Systems Department is responsible for assisting electric utility companies and state and federal agencies in evaluating, and seeking constructive solutions for, environmental problems associated with power generation and transmission. One such project is a joint task force formed by Westinghouse and the Consolidated Edison Company of New York to study beneficial uses of waste heat from generating stations in cities.

Icebreaker Has Gas-Turbine Power

The icebreaker *Norman McLeod Rogers*, latest addition to the Canadian Coast Guard Service, is the first icebreaker to use gas turbines for propulsion power. Its twin 4400-hp gas turbines, designed and built by Canadian Westinghouse Company Ltd., supply the large amounts of reserve power needed for the rigorous icebreaking duty.

The ship has successfully completed sea trials. Its initial icebreaking duties were in the Gulf of St. Lawrence; later it will provide Arctic escort service.

Computer-Aided Mass Spectrometry Facilitates Chemical Analysis

Of the many scientific techniques used in quantitative analysis, one of the most exact is mass spectrometry. However, interpretation of the data produced by the spectrometer has involved lengthy desk calculations that are subject to error. To help overcome the problem, scientists at the Physical Chemistry and Computer Sciences Departments of the Westinghouse Research Laboratories have developed a computer program combination, DCREATE and MSPC4, that gives accurate and error-free analytical results in a much shorter time, especially in analysis of complex materials.

Left—**Largest railroad car sets out on its first delivery of a generator for an electric-utility plant. The car can carry generators weighing up to 1,200,000 pounds.**

Right—**The first icebreaker with propulsion power supplied by gas turbines is the *Norman McLeod Rogers*.**

Both are written in the BASIC computer language. The DCREATE program is used to acquire a memory file of data on pure gases; it serves as an expandable dictionary in which data on a new gas can be added at any time. The data include the gas name and its mass-spectral identity expressions, which are known as the sensitivity coefficient, pattern coefficients, and corresponding mass-to-charge ratios.

The MSPC4 program performs the mathematical functions necessary for obtaining the composition of a gas sample. Preliminary qualitative data for it are obtained by examining the oscillogram (the output of the mass spectrometer) for characteristic ion patterns of gases. When the analyst has identified each gas appearing on the spectrum, he collects the numerical input data for each. He need select only a single representative ion peak height and the respective mass-to-charge ratio; it is usually the one for the gas's parent ion (the most abundant). He also enters the volume, weight, and pressure of the whole gas sample.

The computer then assembles a set of simultaneous equations whose elements consist of the entered peak heights and the gas pattern and sensitivity coefficients called from its memory disc. Actual processing time to assemble and solve the matrix of simultaneous equations amounts to only a few seconds. (In contrast, desk solution of a moderately complex matrix could easily consume several days.) The output is printed in terms of each gas's partial pressure, mole percentage, cubic centimeter–atmospheres, and the sum of the calculated partial pressures.

A number of features written into the MSPC4 program facilitate recognition of any input/output errors. For instance, any gas that has initially been suspected and entered, but found by the program not to be present on the basis of the overall data, is printed out as having a negative partial pressure. If data on an entered gas was not stored in the dictionary file or if a typing error was made on an entered gas, the printout, "gas not found in dictionary," results. Printout of a calculated partial pressure sum of a lower value than that observed (input sample pressure) indicates one or more components missing from the input data. An optional matrix print statement allows quick recognition of compilation errors or of incorrect data in the dictionary.

A program capable of calculation and storage of new calibration data for the memory file will soon be in operation at the Research Laboratories. The analyst will only need enter the pure gas name and the various ion peaks with their respective mass-to-charge ratios; the pattern and sensitivity coefficients will then be calculated and filed by the computer. In conjunction, a search program will be developed. Its input data will include the peaks and mass-to-charge ratios of all the ions appearing on the oscillogram plus the usual system information of weight, volume, and pressure. Since spectral data will be entered as it appears on the sample's spectrogram (every ion's peak and mass-to-charge ratio), all of the data will be totally computer-interpreted, resulting in analyses of even greater precision.

Services for Industry

Nondestructive testing systems are provided in a service that includes design, engineering, procurement, fabrication, assembly, supervision of installation, and training of operators. Testing methods include penetrating radiation, sonic, ultrasonic, magnetic particle, infrared, thermal, eddy current, liquid penetrant, leak testing, and acoustical volumetric techniques. The Laboratory's testing capability stems from its work on the nuclear rocket and other highly technical projects in which nondestructive testing is important. *Nondestructive Testing Systems, Westinghouse Astronuclear Laboratory, Large, Pennsylvania 15236.*

Blueprint reading course gives the knowledge and skills needed for understanding engineering drawings. The course is self-instructional. It starts with simple concepts and progresses to more complex symbols, terminology, and abbreviations. *Westinghouse Learning Corporation, 5809 Annapolis Road, Bladenburg, Maryland 20710.*

Products for Industry

Vertical pump motors are now available in two new frame sizes covering ratings from 200 to 400 hp. The ac induction motors are smaller and lighter than those previously available at these ratings. Each can accommodate a pump head as small as 16½ inches in diameter, allowing use of heads that are smaller and less expensive than those commonly required with motors in this horsepower range. Totally enclosed fan-cooled design is available in the 447TP motor; weather-protected dripproof design is available in the 449TP motor. Both are designed for use with turbine pumps, and both have thrust capacities up to 15,000 pounds at 1750 r/min. *Westinghouse Medium AC Motor and Gearing Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Day-night TV system provides 24-hour surveillance with no operator adjustments required. The closed-circuit system automatically adjusts to outdoor light conditions ranging from the brilliance of a sunny afternoon to the darkness of a moonlit night. Called EYE-24, the system is designed for security surveillance of locations threatened by illegal entry, thievery, and vandalism. The TV camera contains a vidicon tube coupled to an electronic image intensifier tube; that combination, used with an automatic iris, produces good pictures at any hour. Remotely controlled accessories can be added to pan and tilt the camera and to zoom the lens. *Westinghouse Specialty Electronics Division, 7800 Susquehanna Street, Pittsburgh, Pennsylvania 15221.*

Battery-powered ambulance for factories, airports, resorts, etc. takes first-aid and rescue equipment to the scene of the accident, and it has a stretcher deck to transport an injured person to where a conventional ambulance can pick him up. A seat allows a passenger or nurse to ride next to the stretcher to administer aid. Vehicle is 115 inches long, 46 inches wide, and 44 inches high. A 4½-hp motor powers it at speeds up to 12 mi/h. *Westinghouse Repair Division, 26701 Redlands Blvd., Redlands, California 92374.*

About the Authors

Dr. James H. Wright is Director, Environmental Systems Department, Westinghouse Power Systems. His overall responsibility is to develop and coordinate the Company's programs in environmental activities, including the assisting of electric utilities in analyzing and interpreting environmental problems associated with electric power production and transmission.

Dr. Wright graduated from Texas Technological College in 1948 with a BS degree in chemical engineering. He joined Gulf Oil Corporation in the production division, serving as a chemist and later as plant engineer and assistant plant superintendent. He helped develop and operate the first industrial desulfurization plant for natural gas and then, in a further conservation move, led his company to pioneer in conversion of the concentrated hydrogen sulfide gas to marketable elemental sulfur.

As a result of this and related work, he was awarded a fellowship at the Mellon Institute of Industrial Research. There he continued his work in desulfurization of petroleum and discovered a process for removing nickel and vanadium from petroleum and fuel oils. He also earned his MS and PhD degrees in chemical engineering.

Dr. Wright joined Westinghouse in 1956 as a fellow engineer in the reactor physics section of the Atomic Power Division, and, in 1958, he became Manager of Advanced Reactor Systems. When the Advanced Reactors Division was formed in 1966, Dr. Wright was appointed its Technical Director. The following year, he was made Senior Consultant to the Executive Vice-President, Nuclear Energy Systems. He assumed his present position when the Environmental Systems Department was formed late last year. Dr. Wright has served as an appointed member of the Advisory Panel for the Select Committee on Government Research, U. S. House of Representatives, and he was a member of the U. S. Atomic Energy Commission's initial technical mission to the Soviet Union.

W. E. Feero and **J. A. Juves** write about electric-utility relaying analysis out of their experience in Advanced Systems Technology, Power Systems Planning.

Feero graduated from the University of Maine in 1960 with a BSEE degree and joined Westinghouse on the graduate student training program. He worked first in the Analytical Department, participating in dynamic analysis, lightning, and switching studies. In 1962, he joined a task force to develop a digital computer program for applying, setting, and coordinating protective devices in power systems.

Feero was transferred to Electric Utility Engineering (now Advanced Systems Technology, Power Systems Planning) in 1964. There he used the program he helped develop in studies of utility and industrial power systems. Now in the research and development section of Advanced Systems Technology, he is responsible for the Anacom, mobile switching surge laboratories, and development of digital power-system transient analysis programs. He earned an MSEE degree at the University of Pittsburgh in 1969 and is a member of the Relay Committee of the IEEE Power Group.

Juves was born in Havana, Cuba, and attended the University of Puerto Rico, Mayaguez Campus. He graduated in 1967 with a BSEE degree, came to Westinghouse on the graduate student training program, and joined the systems analysis section of Advanced Systems Technology. He works on problems of relaying and digital transient analysis. Juves is a member of IEEE and of its Puerto Rican branch.

Gordon L. Kilgore graduated from Carnegie Institute of Technology in 1960 with a BSME degree. He joined Westinghouse on the graduate student training program and was assigned first to the New Products Laboratory. In 1963, Kilgore moved to the Computer Systems Division (a forerunner of the present Hagan/Computer Systems Division) as an application programmer in metals industry engineering. He was made Projects Manager in 1966.

Kilgore joined a product development group in the Division in 1968 and, since then, has been performing technical and administrative liaison with other Westinghouse divisions that are developing products built around the Prodac 2000 computer system. He has contributed to the application of computers to rolling mills, arc furnaces, and many manufacturing processes.

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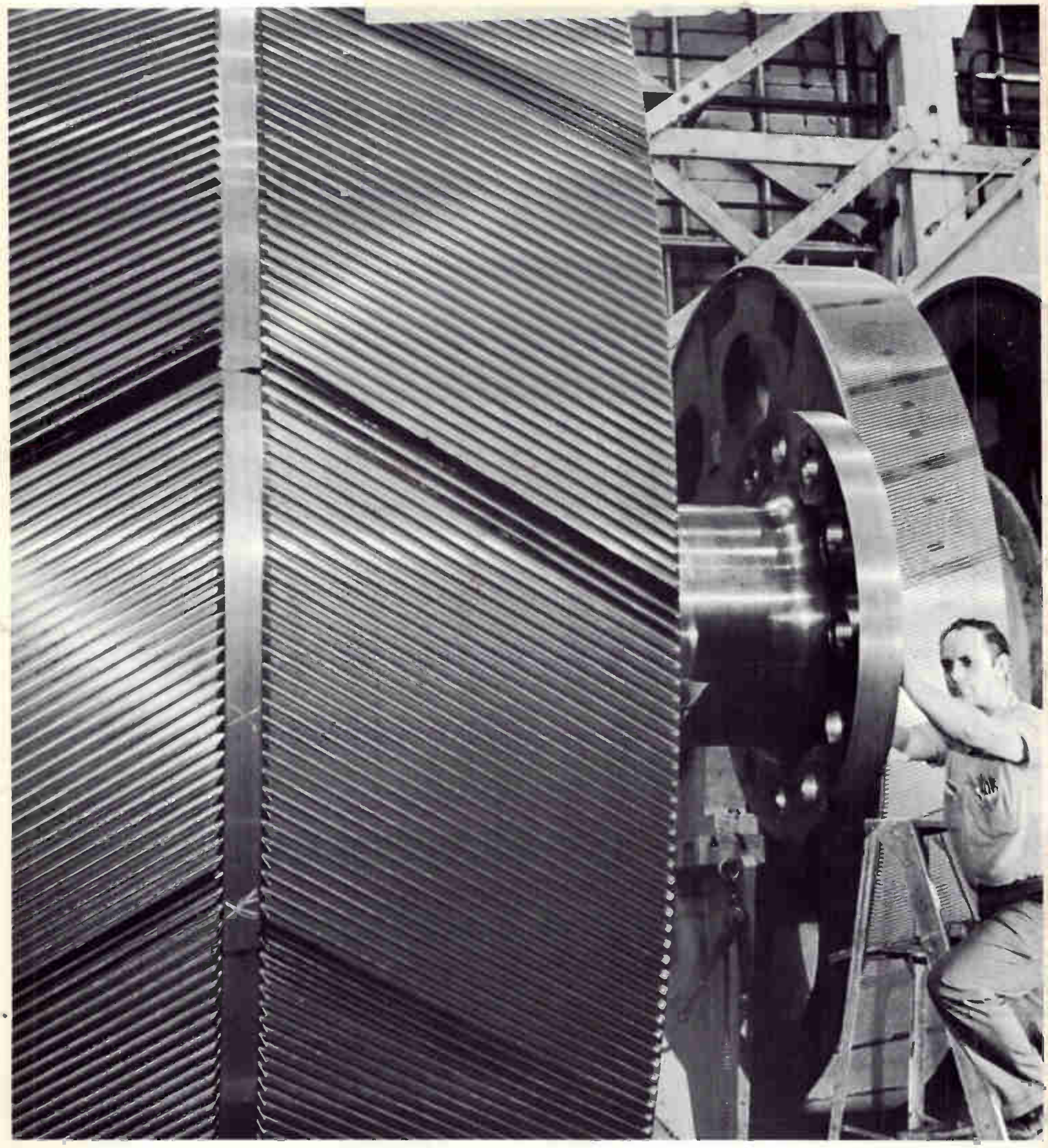

Reduction gears for containerships. (Information on contents page.)