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THE SAFETY AND ENVIRONMENTAL EFFECTS OF NUCLEAR POWER PLANTS

By

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B.S.E., Florida Technological University, 1972

RESEARCH REPORT

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ABSTRACT

The nuclear power plant has given new direction to power generation. It offers a new source of heat. The heat can now come from the fission of atomic fuel and not from the burning of fossil fuel.

Safety and protection from the possible hazards of radioactivity generated by nuclear power plants is a completely new and untested area. The damaging effects of thermal pollution have only recently been ~~brought~~ out to world with ~~and~~ the technology to correct ~~them~~ it lagging far behind. Emergency systems and over-designed construction are only part of what has to be done to make absolutely certain such accidents if they occur, will be contained allowing no harmful radioactivity to reach the environment. Handling of radioactive wastes is very critical in a nuclear power plant. These wastes have to be storaged in protective containers and transported to predetermined storage sites. At these sites the containers of radioactive wastes are lowered into large salt mines.

Licensing and regulation of nuclear power plants during construction and operation is the responsibility of the Atomic Energy Commission. The five member federal panel has issued strict requirements that must be met in each step in the process of obtaining permits and licenses, construction, and generation.

Waldron M McLellon
Waldron M. McLellon, PhD, P.E.
Committee Chairman

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Purpose

The purpose of this research report is to collect and present a summary of readily available data that will be helpful in informing on safety and environmental effects that nuclear power plants will have on man and his environment. A second purpose is to create an awareness of the great need for nuclear power in the 21st century. This report is the result of a great desire, on the part of the writer, to learn as much as possible about present and future positions of nuclear power plants and how they will co-exist in and around the community of today and tomorrow.

Scope

The research of this report was largely conducted through an extensive library search of books, magazines, and newspapers. Information was obtained from the Atomic Energy Commission, educational papers of environmental nature and from construction contractors. Much literature was found concerning the safety of nuclear power plants from the standpoint of a major accident and from the future effects of stored radioactive waste materials.

This report includes an overview of nuclear power plants power generation and their important role in this country's future. This report also includes technical information relating to nuclear power plant construction, operation and handling of radioactive materials, and transportation and storage of radioactive wastes. Finally, conclusions are submitted based on the findings for further research and study.

NUCLEAR POWER

Nuclear Power - General

The subject of this report is the safety and environmental effects of nuclear power plants, operation by which is meant plants operated by utilities to supply electricity to their customers. Its purpose is to present factual information on a number of topics relating to this subject.

About 80 per cent of the electricity used in the United States is produced in steam-electric power plants. These are the plants in which heat from the combustion of coal, oil, or natural gas (the fossil fuels) converts water to steam. The steam is then used to drive a turbine generator and thereby produce electric power.

The nuclear power plant is a new kind of steam-electric plant in which the heat comes not from the burning of a fossil fuel, but from the fission of an atomic fuel, the basic source of which is uranium. The turbine-generator part of a nuclear power plant is similar to that of an ordinary steam-electric plant; and the product, electricity, is identical.

There are two principal incentives for developing and using nuclear power. First, it promises to reduce the cost of generating electricity in sections of the country that are distant from coal mines or oil or gas fields and therefore bear high fuel transportation costs. Examples are the Northeast and the West coast where fuel costs typically account for about half the total cost of power generation. Nuclear power is already benefiting these sections by making a competitive energy source acceptable to them.

The second reason is that nuclear power promises ultimately to be an indispensable energy source, nation-wide. While United States reserves of fossil fuels (especially coal) are large, our rate of consumption is increasing rapidly. This is true not just in electrical power generators, which presently account for about one-fifth of our fuel consumption, but also in transportation, manufacturing, heating, and other activities in which fuel is consumed in large quantities. Altogether, it has been estimated that we will use as much energy from fuel over the next twenty years as we used from the American Revolution to the present day. When projected increases in the rate of energy consumption are taken into account, the indications are that we would deplete our fossil fuel resources in only two or three generations if we were to continue our present pattern of fuel utilization. In 1972, we used 30 per cent more fossil fuel than what was produced for power generation (60 billion barrels) (American Broadcasting, 1973). The use of nuclear fuels for generating electric power will help conserve fossil fuels and will greatly extend our energy resources for the future.

Nuclear Power Today

United States development of nuclear power began in 1954, when the Congress passed legislation permitting utilities and others besides the Federal Government to own nuclear reactors (Lish, 1972).

Since 1954, a total of about 19 million kilowatts of atomic power capacity has been placed into operation; plants with an additional 51 million kilowatts of capacity are in an advanced state of construction and an additional 86 million kilowatts of capacity are now being designed. These numbers are small in relation to the total amount of United States electric generating capacity, which is currently almost four hundred million kilowatts. They, nonetheless, represent a significant amount of power.[2] Figure 1 locates nuclear power plants in the United States today. The total capital investment made or committed to date by United States utilities for nuclear power operation facilities has reached and gone over the one billion dollar mark.

Jacksonville, Florida, has been chosen as the site for a new $200 million manufacturing facility which will build platform mounted nuclear power plants on an assembly line basis. These plants will be capable of withstanding salt water exposure and the force of the ocean for the life of the plant. The plants will be rated at 2,000 megawatts of output and weigh 140,000 tons (Florida, [3]1972). The environmental effects from floating nuclear power plants would be greatly reduced as compared to conventional onshore plants.

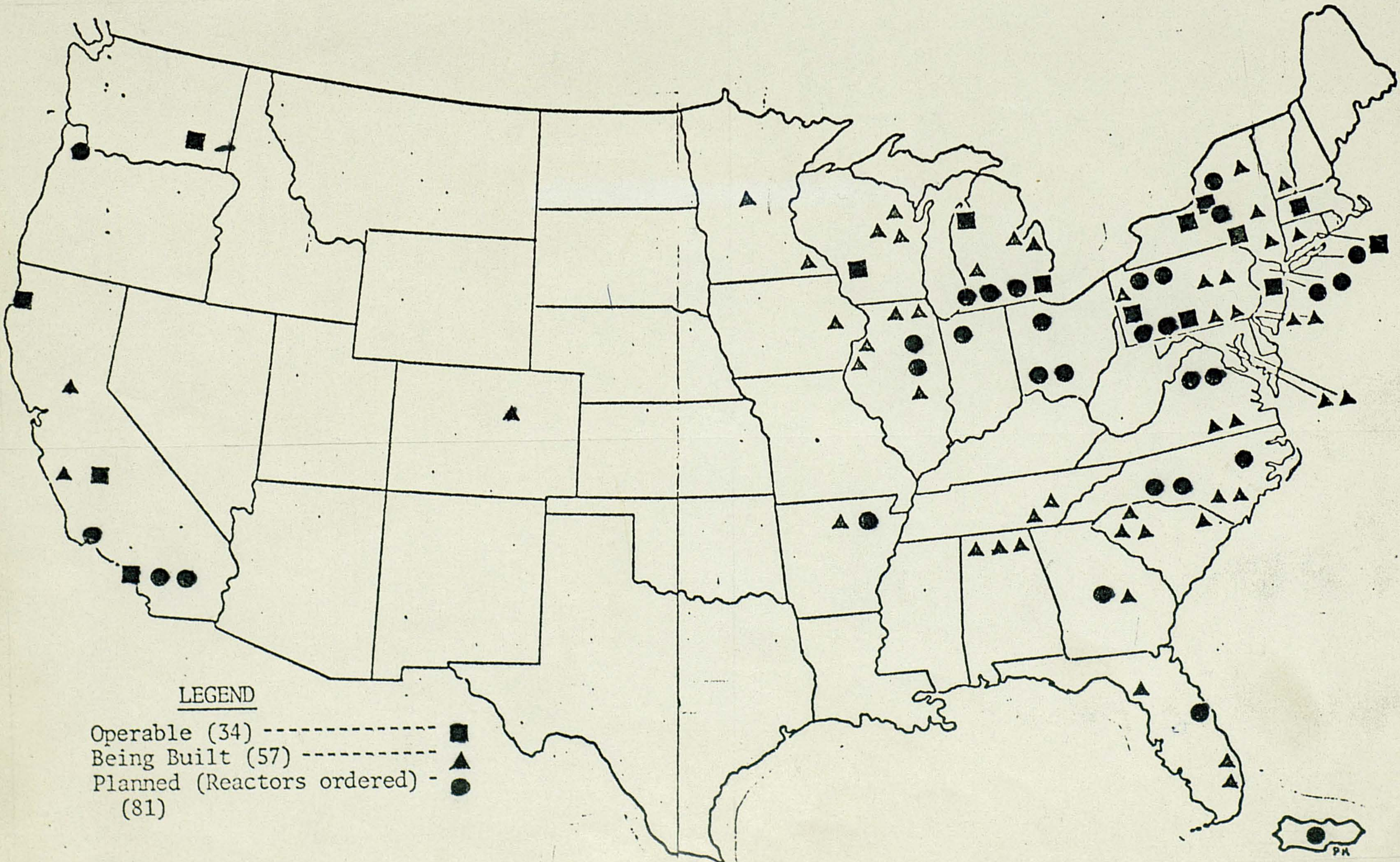

Figure 1. Nuclear Power Reactors in the United States (Supplied by Atomic Energy Commission, June 30, 1973)

SAFETY

Safety and Radiation

It should be understood at the beginning that it is physically impossible for a nuclear power plant to behave like an atomic bomb. In the latter, pieces of essentially pure fissionable material are rapidly compressed into a dense mass which is forcibly held together for an instant of time to enable the chain reaction to spread through it. These conditions do not and cannot exist in the reactors used in nuclear power plants. They use relatively dilute fuel; they are designed along different principles; and they operate differently.

The safety of nuclear power plants does not depend on restraining the force of nuclear energy but on containing the radioactive material it generates.

The fission process requires a particular kind of heavy element, such as uranium or plutonium, as a basic material. Natural uranium is a mixture of three isotopes, atomic forms that are chemically alike but vary in mass. An atom of one of these isotopes, uranium-235, can readily undergo fission when a free neutron strikes its heavy central nucleus. The nucleus breaks into two pieces that fly apart at high speed; in addition, two or three new neutrons are released. The kinetic energy of the flying fission fragments is converted to heat when they collide with surrounding atoms, and the new released neutrons cause a chain reaction by initiating new fissions in other uranium-235 atoms.

The principal radioactive materials generated are the "ashes" of fission - the so-called fission products. A reactor generating 1 million kilowatts of electrical power for one year will produce 1200 kilograms of fission products, which one day after shutdown has an activity equal to some three billion curies (3) (Moeller, 1969). The products are a diverse mixture of substances. Some of the radioactive fission products that are produced are radioactive iodine-131, radioactive strontium-90, strontium-89, radioactive cesium-137, and radioactive krypton-85 (Simpson 4, 1972). Some are gases, some are solids. Some have short radioactive half-lives, some have long half-lives, and some are stable (non-radioactive). The quantity of fission products formed is small in terms of man - only a few pounds a day in a big plant - but large in terms of radioactivity. As the plant operates, the reactor's inventory of radioactive fission products builds up gradually until a point is reached at which the rate they lose radioactivity just about offsets the rate at which they are formed and then it essentially levels off. All but a very small amount (less than one-thousandth of one per cent) of the material normally remains confined within the fuels.

Small additional amounts of radioactive matter, called activation products, are formed in a nuclear power plant by exposure to neutrons (Lish 5, 1972). This only happens in and around the reactor core, which is the only part of the reactor where many neutrons are present. Most activation products have very short half-lives and are of minor importance in relation to fission products.

The basic unit for expressing amounts of radioactivity is the curie. One curie of radioactivity is equal to a certain very large number (37 million) of atomic desintegrations per second. This relationship has little absolute meaning when applied to a mixture of radioactive substances such as fission products. The reason is that different kinds and strengths of radiation are given off by different radioactive materials. For example, one kind (alpha particles) is blocked by an ordinary piece of writing paper, while another kind (gamma rays) can penetrate several feet of concrete.

Radiation Detection and Measurement

A very important aspect of radioactivity is its detection and measurement. The presence of atomic radiation (undetectable by human senses) is readily detected by several types of instruments. One of the simplest radiation detectors is ordinary photographic film, which darkens on exposure to radiation. It is used in the form of film badges as a means of measuring the cumulative amounts of exposure received during a given period by employees in nuclear power plants (Lish, 1972). Other types of detectors such as geiger counters are used to detect the presence and measure the intensity of atomic radiation.

Radiation detection is also very sensitive in another way - it's able to identify specific radioactive substances. This is made possible by the fact that every type of radioactive atom has a characteristic pattern or radioactivity.

Those who operate nuclear power plants can, through the use of radiation detection and measurement instruments, maintain an extremely close check at all times, not only on radiation levels in and around the plant but also on the identity and amount of any fission products present in plant effluents.

Radiation Safety Standards

The problem of balancing risks against benefits in nuclear power plants takes the form of radiation safety standards.

The standards which govern acceptable practice in atomic power plants are determined by the Atomic Energy Commission (AEC) as part of its statutory responsibility under Federal law. In setting those standards, the Atomic Energy Commission receives official guidance from the Federal Radiation Council (FRC), whose recommendations are subject to the approval of the President and whose membership includes the Secretaries of the Department of Health, Education, and Welfare, Defense, Commerce, Labor, Agriculture, and the Chairman of the Atomic Energy Commission. Also, the AEC has the assistance of the National Committee on Radiation Protection and Measurements, and of several advisory committees which the AEC has established.

The Federal Radiation Council has recommended that whole body radiation exposure of members of the general public not exceed 500 millirems per year. The millirem (~~one thousandths of a rem~~) is a standard measurement that takes into account the properties of the kinds of radiation involved. The AEC's radiation safety standards are designed accordingly. The AEC's basic radiation safety standards are published in the Code of Federal Regulations and are, in fact, laws.

Other numerical guidelines are that nuclear power plants must be designed to limit radioactivity in effluents to levels that would keep resultant radiation exposures of persons living near the plants to less than 5 per cent of the average natural background radiation (Nuclear Power, 1972). Natural background radiation comes from naturally radioactive substances. These substances are present in common place materials, such as granite, and also in the human body. Part of the potassium and carbon in the body, for example, is radioactive. The average exposure from natural background radiation in the United States ranges from 100 to 125 millirems per year. Thus, the 5 per cent level would be about one per cent of the federal radiation protection guidelines of 500 millirems per year.

CONTROL OF RADIOACTIVE MATERIAL DURING OPERATION

The Reactor Core

A large water-cooled reactor contains 50 to 100 tons of fuel. The fuel material most commonly used today is slightly enriched uranium dioxide (UO_2) in the form of small cylindrical pellets. The heat from fissioning a pound of U-235 (less than one per cent of whole uranium) is large, with the ultimate thermal potential of 1.4 thousand tons of coal or 6,000 barrels of oil (Garney, 1972). The pellets are placed in thin-walled metal tubes to form fuel rods, a number of which are bundled together in a long metal can to make up an assembly known as a fuel element. A number of these are positioned in a pre-determined grid to make up what is known as the reactor core. The core is contained in a massively constructed steel tank, known as the reactor vessel, through which cooling water flows (Lish, 1972).

The supply of fission products in the plant, after several months of operation, amounts to several hundred pounds. The fission products are, of course, found inside the fuel. On a weight basis, in excess of 99.99 per cent of the fission product supply of the plant normally remains confined within the fuel elements. It is difficult for the fission products to leave the fuel. There are two reasons for this fact. First and most important, it is the nature of uranium dioxide to hold onto the fission products. Second, fission products which manage to break loose from the uranium dioxide must find a way to get past the fuel cladding (the metal tubes) in order to get out. Those that do get out of the fuel enter the coolant.

When the time comes to refuel the plant, which is done annually, the reactor is shut down and the top of the reactor vessel is removed. A crane is used to lift out the spent fuel elements and move them to a storage vault or pool. There they are left for several months to allow for the shorter-lived radioactivity to subside. By the end of this cooling off period, nearly all of the gaseous fission products have lost their radioactivity. The fuel elements are then loaded into ruggedly built lead-shielded steel containers for shipment by truck, rail or barge, to a plant where they will be chemically processed to recover their unused fuel content for future use. It is at the processing plant that the fission products contained in the fuel elements are removed, concentrated and stored, except krypton-85 which is released as a gas to the atmosphere.

The Coolant System

There are two basic types of water-cooled reactors - pressurized water reactors (PWR) and boiling water reactors (BWR) (Forman, 1970). In the former, the reactor cooling water or primary coolant is kept under sufficient pressure to keep it from boiling in the reactor vessel. On leaving the reactor vessel it passes through a steam generator in which it gives up its heat to a separate stream of water or secondary coolant, thereby converting the latter to steam; then it flows back to its reactor (see Figure 2).

In a boiling water reactor the flow pattern is different. In this case, the reactor cooling water is allowed to boil in the reactor vessel so that the steam is generated in the reactor (Gofman, 1971). Additional steam may be generated in a separate heat exchange similar

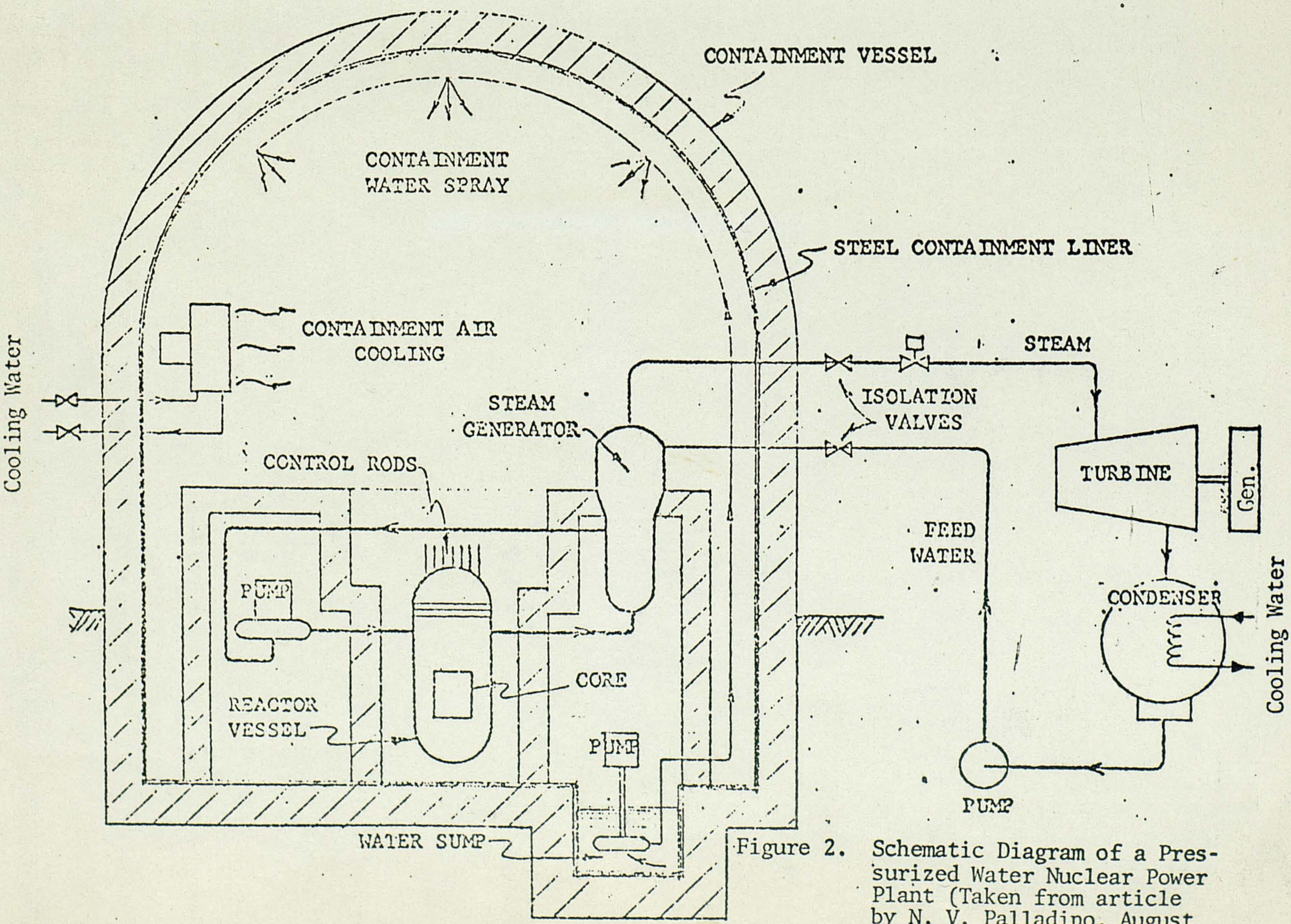

Figure 2. Schematic Diagram of a Pressurized Water Nuclear Power Plant (Taken from article by N. V. Palladino, August 21, 1970)

to that in a pressurized water plant. This steam goes to the turbine, is condensed, and the condensate is returned to the reactor vessel.

It is important to understand that in both systems the primary coolant circulates within a closed equipment circuit and is completely cut off from its original source, such as a river, lake, or ocean. In fact, in all commercial nuclear power plants, the only water that goes from a waterway into the plant and then empties back directly into the waterway is that which is used to cool the turbine condensers. This water does not flow through the reactor. Its sole purpose is to carry non-usable heat away from the plant.

As the power plant operates, the reactor cooling water picks up some radioactivity. One source is leakage of some fission products through minute imperfections in the fuel element cladding. These fission products, amounting to something like one-thousandths of one per cent of the fission product supply of the plant, are principally the gaseous and more easily vaporized solid parts of the fission-produced mixture. Another source of radioactivity in the reactor cooling water is activation products. These include activation products formed in the water, most of which have a very short half-life (an example would be radioactive nitrogen which has a half-life of only a few seconds) (Lish, 1972) and activation products. These are found in reactor structural materials and enter the coolant through corrosion or erosion.

To maintain the purity of the water and to limit the amount of radioactivity in the primary cooling system, the reactor coolant is purified. This is done by draining off a portion of the primary coolant flow, passing it through purification equipment, and then returning it to the system (Gofman, 1971).

Radioactive Waste Handling at the Plant Site

In addition to processing a portion of the primary coolant flow, the coolant purification system may also handle water collected from other points in the reactor system (for example, water that has leaked out of equipment, or that has been used to clean out equipment during maintenance operation). The purification is done by means of evaporation, demineralizers and filters.

All but a small fraction of the solid or liquid radioactive substances removed during the purification process are collected as waste concentrates, which are then stored. The balance, averaging a few millionths of a gram per day during routine operation, is discharged to the waterway serving the plant in a dilute waste stream in amounts which meet the AEC standards for drinking water. Further dilution occurs as the waste stream is mixed in the waterway.

The radioactive gases removed during the purification process average a few hundred thousandths of a gram per day during routine operation. This material is released to the atmosphere through a tall chimney on a controlled basis to assure that there is sufficient dilution and atmospheric dispersion of the radioactivity to meet AEC regulations, which are based on an annual radiation exposure that might be received by persons living at and around the plant site.

The radioactive waste concentrates from the purification process, together with other miscellaneous solid wastes are encased in concrete and steel barrels. When a sufficient number of barrels accumulate, they are shipped from the plant to an AEC approved site for burial or long-term storage.

THE NUCLEAR ACCIDENTS

Nuclear Excursions

The power level at which a reactor can operate safely is limited by the capacity of its cooling system; Therefore in other words, the rate at which the primary coolant can carry away the heat generated in the reactor core. If the heat were to be generated at a faster rate than it is carried away by the coolant, the fuel would overheat and could melt or even vaporize. The consequences might range from heavy radioactive contamination of the coolant (through the release of fission products from another fuel) to damage to the reactor equipment and some release of radioactivity from the primary reactor system into the plant containment system.

Therefore, one type of accident that is taken into consideration during design is that of nuclear excursion - an accidental increase in the rate of fission chain reaction. This also would cause high temperatures to be reached in the fuel and cause chemical reactions between reactor material that would increase the amount of energy involved.

Natural Safeguards

Nuclear reactors tend to slow themselves down when nuclear excursions occur. Several factors contribute to this characteristic. The most important factor is called the "Doppler effect" (Forman, 1970). This is a complex phenomenon. When the temperature of the fuel rises, the proportion of neutrons captured by non-fissioning atoms increases and the rate of fission tends to slow down. The "Doppler effect" is not only automatic but instantaneous, and offers immediate resistance to any increase in reactor power level.

A second factor is that as the fuel becomes hotter, its density decreases slightly, which also acts to lower its reactivity.

Thirdly, in water-cooled reactors, the water that flows through the reactor case, besides carrying away the heat, serves also to moderate the neutrons and encourages the fission chain reaction. Just as the fuel density decreases, with increasing temperature, so does the density of the water which again lowers the reactivity.

In normal operation, the temperature of the fuel cladding is kept well below its melting point (Lish, 1972). Then the fuel temperature can rise and fall during an excursion without affecting the make-up of the fuel elements.

Design Safeguards

To understand how reactors are controlled, it is necessary to explain what is known as "excess reactivity." To start a reactor and maintain normal operation, more fuel than is required for a fission chain reaction must be added to the reactor. This extra fuel furnishes excess reactivity against which the system can draw to sustain the chain reaction as the reactor operates.

For normal operation, there must be a means of compensating for the excess reactivity that is present in the reactor core. In other words, there must be a way of controlling the rate at which the excess fuel is consumed. This is done by adding "negative reactivity" in the form of substance that absorb neutrons. By moving these substances into and out of the reactor core with adjustable control rods, the amount of neutrons in the core can be decreased or increased, thereby slowing down or speeding up the reaction.

Reactors controlled in this way are equipped with a number of control rods, some of which are used only for emergency shutdown of the reactor. In many reactors, solutions containing neutron absorbers, such as borax, are added to the primary coolant, either for routine control or for use during shutdown (Lish, 1972). All reactors are equipped with instrumentation to monitor the amount of neutrons in the reactor core. This instrumentation is what controls the adjustment of the control rods in the reactor. In emergency situations where the core is overloaded with neutrons, the control rods can be lowered into the reactor quickly thereby shutting down the reactor.

Similarly, other instruments monitor other aspects of the reactor operation, such as the level of coolant in the reactor vessel, the temperature of the coolant leaving the reactor vessel, and the pressure of the primary reactor system. All these instruments can trigger a rapid shutdown of the reactor. If a power failure should occur, mechanical devices will take over and insert the control rods into the reactor core. Yet another safeguard takes the form of emergency standby desiel generators. The Florida Power Corporation nuclear plant at Crystal River has two such units.

Failure of Cooling System

Overheating of the fuel could also be caused by an interruption in the flow of coolant through the reactor core when the reactor is operating in a normal manner. Also, once the fuel has been in service in a reactor it continues to give off heat when the reactor is shut down and even after it has been removed from the reactor. This results from the radioactivity of the fission products and, while not nearly as intense as the heat that is generated during reactor operation, it could lead to melting of the fuel elements if cooling were not provided (Gofman, 1971). Instruments monitor the coolant system and in cases of either minor leaks or of out-right loss of coolant, the reactor is automatically shut down. Also, a standby coolant system is provided to cool the reactor core during reactor shutdown in the case of loss of coolant. this is good, but [illegible]

Emergency core cooling systems (ECCS) are intended to cool a reactor's extremely hot core in the event that it loses its normal coolant through a ruptured pipe, a broken weld, or a key valve opened in error. Experts call this type of accident "the maximum credible accident" that a reactor can possibly sustain (Gillette, May 1972). Deprived of the cooling water, a reactor's core temperature would quickly rise to the melting point of the fuel element metals. Within an hour a large reactor core could melt and drop to the floor of the reactor vessel.

Experts say that a loss of neutron moderating water would prevent a nuclear excursion from occurring, but residual heat in the core - plus heat released by decaying fission products in the fuel and by violent chemical reaction between metal and remaining water - could still amount to 50 megawatts of energy. This would be more than enough to allow the core to melt through the steel reactor vessel, and to carry it through tons of concrete and steel below, within another hour or so. Beyond this point, the molten core could just keep going (Gillette, May 1971).

Experiments are being conducted as part of the preliminary work leading up to research with the Loss of Fluid Test (LOFT) facility in Arco, Idaho, a $35 million domelike structure in which the AEC will progressively starve a 55 megawatt reactor of cooling water and measure its behavior (Gillette, September 1972). The LOFT project started in 1963 at a projected cost of $18 million. The LOFT experiments, which are scheduled to begin in 1975, will provide the first test of an emergency core cooling system under actual operating conditions. (By 1975, 80 nuclear plants could have used the results of these experiments.) The model is designed to lose its cooling system and melt revealing what would actually happen in the worst type of accident. The facility is now 80% complete and by no means ready to be used. With the costs running toward the $35 million mark, allowing the unit to destroy itself is beginning to create many skeptics within the atomic energy field.

Another project in Idaho is the Power Burst Facility (PBF) (Gillette, September 1972). It was completed in the summer of 1972. Completion was four years late with 100% overruns at a cost of $8 million. Its purpose is to subject nuclear fuel facilities to abnormal stress conditions and to observe fuel rods before and after an accident. There are conflicts of opinions on all sides as to overruns, delays, objectives and goals of these two projects.

One experiment has shown (using a small scale model) that when loss of coolant occurs, high steam pressures within the reactor vessel actually restrain all but about 10% of the emergency cooling water from entering the vessel (Gillette, May 1971).

Another experiment showed that temperatures of some of the fuel elements may go higher as a result of loss of coolant than had previously been expected. This is a matter of concern because the higher a fuel element's temperature rises, the more likely it is to rupture, spilling intensely radioactive fission products into the reactor vessel. Moreover, the higher temperature of the fuel rods, which are typically clad in zirconium alloy, would intensify a chemical reaction between the metal and the cooling water. This would release hydrogen, generate still more heat, and thus place an even heavier demand on the emergency cooling system.

Accidental Criticality

Accidental criticality refers to the possibility of a fission chain reaction starting by accident (Gofman, 1971). A chain reaction could start in an amount of fuel considerably less than a full reactor load. The answer to this type of accident is "safe geometry," which means ensuring that a critical mass cannot be assembled under any circumstances. The safeguards include designing shipping containers so that it is physically impossible to load an unsafe number of fuel elements into them, and equipping fuel storage vaults with spacer devices so that safe geometry is assured.

Vapor Containment

Vapor containment is the final safeguard against radioactive substances escaping from the plant to the environment (Forman, 1970).

The basic concept of vapor containment is that it will endure the maximum credible accident. This type of accident would have to occur through multiple failures, such as the sudden and complete loss of the primary coolant, the failure of the emergency cooling system to operate and the overheating and melting of the fuel elements. Thus, the vapor containment shell would have to withstand the extreme pressures and all of the radioactive substances that would be released.

There are two types of vapor containment systems used today in nuclear power plants using water-cooled reactors.

One type makes use of a large spherical or cylindrical steel shell that encloses the entire reactor. The shell, which in a large plant might be the height of a twenty story building, is constructed by welding together sections of steel plate. In plants that are located at a distance from population centers, a single containment shell is used. For plants that are located near or in population centers, more elaborate requirements are used. For example, metropolitan Chicago has, as of last year, five nuclear power plants in operation, two under construction and six on order (American Broadcasting, 1973). Shells for these plants are double-walled, have zero leakage features, and are surrounded by a thick concrete radiation shield. A major accident within this type of a shell would have essentially no effect on the surrounding environment.

A second type of containment system is known as the "pressure suppression system." In this system, the reactor vessel is located in a steel containment tank surrounded by a concrete radiation shield. The containment tank (the dry well) is connected by pipes to a second tank (the wet well) that is partially filled with water. The entire unit is housed below ground level within a specially constructed building. In the event of an accident within the reactor, the vapor would pass into the dry well and from there through pipes into the wet well. The pressure surge would be relieved by the vapor condensation.

The nuclear power plant at Crystal River uses the first type of containment shell or vessel. It is made up of a one inch thick steel inner liner surrounded by a three feet thick reinforced concrete shell. The vessel's foundation is a 27 feet thick reinforced concrete mat. Before operation, the pressure in the vessel is raised to 67 pounds per square inch and held at that test pressure for twelve hours. The vessel is approximately 200 feet tall and 180 feet in diameter.

RADIOACTIVE AND THERMAL WASTES

Nuclear power generation creates problems unique unto itself. Figure 3 shows the course radioactive substances follow from mining through disposal.

Refining and reprocessing of reactor fuels to obtain fissionable components results in the production of several by-products. Most of these isotopes have short half-lives and decay to a safe level in less than a year. Temporary storage is therefore feasible as a means of averting environmental contamination. However, elements such as strontium-90, cesium-137, and plutonium are also present. These have half-lives of hundreds or thousands of years, and constitute a prolonged radiation hazard (Radioactive Wastes, 1972).

By the year 2000, according to present projections, storage will have to be provided for about 27,000 megacuries of radioactive wastes in the United States; these wastes will be generating 100,000 kilowatts of heat at that time.

The wastes will include about 400 megacuries of alpha emitters. Of these, the plutonium-239 with a half-life of 24,000 years will be dangerous for about 200,000 years.

Chemical Reprocessing Plant

At the chemical fuel reprocessing plant, the fuel elements, which have confined the radioactive materials, are dissolved and processed. Most of the radioactive materials are retained in underground

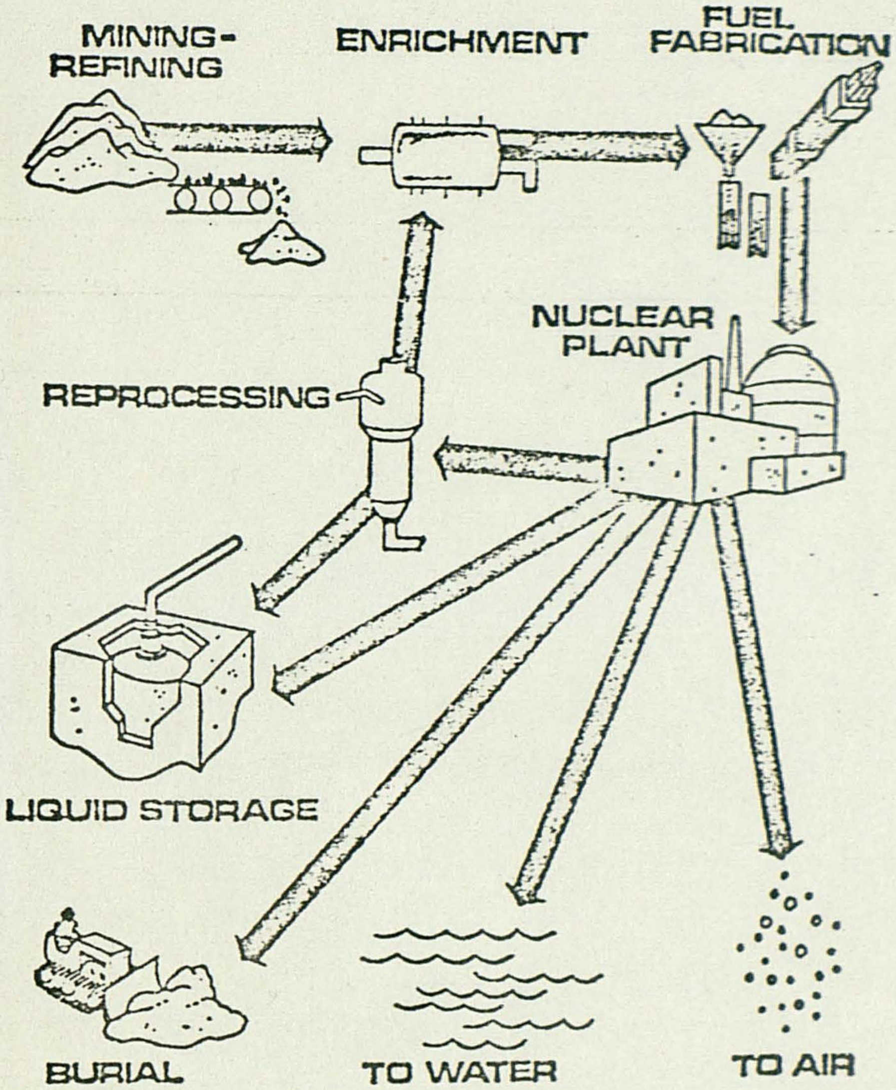

Figure 3. Path of Radioactive Substances from Mining through Disposal (Gofman, 1971)

tanks at the processing site, but three volatile radionuclides - iodine-131, krypton-85, and tritium - may be discharged to the atmosphere. The iodine-131 is substantially reduced by storing the fuel elements before processing. In 100 days, radioactive decay will reduce the iodine-131 content by a factor of 5000 and various waste gas cleaning techniques are then utilized to minimize its discharge into the atmosphere. At present, krypton-85 is discharged to the atmosphere, and most of the tritium is discharged to the environment as water.

Only one commercial plant, the Nuclear Services Plant at West Valley, New York, is currently operating and this only since 1966. During this time, liquid discharges have imposed an average dose of 75 millicuries per year at the boundary. Essentially no iodine-131 has been emitted. As for the other main gaseous effluents, all the krypton-85 and hydrogen-3 contained in the fuel has been released.

Another report listed the releases of this plant to be 14 curies of strontium-90 in waste water and one million curies of krypton-85 vented to the atmosphere (Gillette, June 1971). These figures are below the permitted releases but far exceed the worst case among nuclear power plant emissions.

Technology is now available for reducing liquid discharges, and processes for retaining krypton-85 and hydrogen-3 are being developed at AEC laboratories. Properly operating radiochemical plants in the future should emit no more radioactivity than do properly operating reactors - that is, less than 10 per cent of the natural background radiation at the plant boundary.

Confinement

Long life isotopes can be separated from other nuclear waste components, concentrated, and confined to prevent release of radiation. For example, low level wastes are stored in steel-lined concrete containers and stored 20 feet below the surface. The containers deteriorate slowly and the components decay to safe radioactive levels by the time that significant leakage occurs.

High level wastes are being stored underground as liquids in steel-lined concrete vaults. Such storage has not yet been found to result in release of radioactivity beyond the immediate area. However, leaks have been detected in tanks, so increases in ground water could cause widespread contamination. Research is being conducted on calcinating wastes to granular form or evaporating solutions to produce crystals for storage.

Transport

It is projected that by the year 2000 there should be 10^6 megawatts of nuclear power available, of which two-thirds will be liquid metal fast breeders. From this one can expect 7000 to 12000 annual shipments of spent fuel from reactors to chemical plants, with an average of 60 to 100 loaded containers in transit at all times. Projected shipments might contain 1.5 tons of core fuel which has decayed for about 30 days, in which case each shipment would generate 300 kilowatts of thermal power and 75 megacuries of radioactivity (Weinberg, 1972). Today, a container might contain only 7 megacuries and produce 30 kilowatts.

Design of a completely reliable shipping container is complex. As now conceived, the heat would be transferred to air by liquid metal or molten salt; and the container would be provided with rugged shields which would resist deformation that might be caused by a train wreck. To be acceptable the shipping containers must be shown to withstand a 30 minute fire and a drop from 30 feet onto an unyielding surface.

Storage

Other techniques have been proposed to handle the large volumes of radiocative wastes expected in the future. Separated wastes in stainless steel containers may be placed in caverns excavated in deep metamorphic bedrock. Tunnels which receive waste containers can then be capped, and fractures or fissures in the rock sealed by grouting. The containers would eventually disintegrate. However, leakage would be slow since the hydraulic gradient of bedrock is low, wastes have higher density than surrounding ground water, and components such as plutonium are only slightly soluble. The primary disadvantage is the excavation costs.

Vulcanization

Lawrence Radiation Laboratory has proposed that reactor wastes be vulcanized or incorporated into molten silicate rock. Liquid wastes could be injected into a cavern, blasted at a depth of 2000 ft. with nuclear bombs. The liquids would self-boil and evaporate to solids. If the chimneys are capped, the solids would melt and dissolve into the surrounding rock. This eventually freezes and traps the wastes in a solid matrix (Radioactive Wastes, 1972).

Salt Mines

The main advantages of bedded salt are primarily that, because salt dissolves in water, the existence of a stratum of bedded salt is evidence that the salt has not been in contact with circulating water during geologic time. This is reinforced by the fact that salt has been found to be the best material available because of its seismic stability, compressive strength, ability to conduct heat, high melting point (1450°F), self-sealing ability and shielding property which is similar to that of concrete (Holden, 1971).

Containers of hot solidified high level wastes, which range in size up to 18 feet long and 2 feet in diameter, are transported to the salt mines in railroad cars. They are then lowered down shafts into large rooms that have been carved out of a salt strata. The pressure of the salt, and the heat of the cylinders ranging from 600°F to 900°F, will cause the natural plastic action of the salt, which has the consistency of very hard wax, to seal around the containers. Within a period of months to 10 years the steel covered ceramic containers will disintegrate leaving the salt to hold the wastes in place.

Heat Discharge

In the most efficient fossil fuel thermal power plant, about 40 per cent of the generated heat is turned into power. Most of the remaining 60 per cent is transferred to cooling water in the turbine condensers. For nuclear power plants about 70 per cent of this heat release finds its way to the cooling water. The heat discharged and wasted from the crystal River 800 megawatt nuclear unit is sufficient to increase by 15°F a 200 feet wide, 10 feet deep discharge canal flowing at 7 fps.

The cooling tower is probably the most popular of the corrective measures. Both wet and dry cooling towers are used and there is no heat discharge whatever into surrounding bodies of water.

The most obvious objection to the tower concept is its cost, both capital costs and the increased plant operating costs it imposes. An even stronger objection is its appearance. Large dual towers might only be suitable for industrial parks or rural areas. Another objection to cooling towers is fog, near airports; for example, a vapor plume rising several hundred feet above a tower is not desirable. Also freezing vapor may create icing conditions in the surrounding area. Cooling towers also generate large quantities of steam in a cold climate which is objectionable to neighboring communities.

Off-stream cooling ponds are one alternative for plants of limited water supply. The greatest problem is the availability and cost of land, which may run into several million dollars - 1,000 to 2,000 acres per 1,000 megawatts depending on the economics of the plant.

Dilution is another possibility for keeping down the water temperature in a large water supply. A typical installation is the Oyster Circle Nuclear Plant of the Jersey Central Power and Light Company on Barnegal Bay, New Jersey. Circulating water flows to the condensers of the 640 megawatt Unit #1 at 460,000 gpm; an additional 780,000 gpm is not pumped through the condensers but goes directly from the intake to the discharge canal, forced by three low-head axial-flow pumps (Richards, 1968).

Suitable dispersion of the warm water discharge is usually a minimum requirement for keeping total water temperature within an acceptable limit. Near Richland, Washington, a conduit, 11 feet in diameter flowing at more than 13 fps, carries 564,000 gpm 1000 feet to mid-channel of the Columbia River where it is discharged through four vaned outlets. This discharge serves the 860 megawatt Hanford Nuclear Generating Plant of the Washington Public Power Supply System (Richards, 1968).

Another effective method of dispersing heated water is to discharge it at the surface with a horizontal velocity of 2 to 5 fps. The momentum of this jet if properly directed will carry the heated water several thousand feet into the waterway, almost as effectively as a closed conduit.

It is practical to consider combinations of two or more means of reducing a problem of heated water. For example, the discharge can be passed through a limited area cooling pond or a cooling tower before returning it to the original river source. Of importance also is fish mortality at the intake screens. In some seasons, several tons of fish per day have accumulated on intake screens due to high intake water velocities and brought plant operation to a halt. Other environmental factors include destruction of fish spawning areas during and after the construction of water handling facilities and the alteration of wildlife refuge areas by excavating cooling water canals and ponds.

A point that should be made is that thermal effects from power generation plants do not necessarily cause thermal pollution in cooling waters. In many cases, heated water discharges do not strain the ecosystem of a given river or cooling lake. In cases where proper plant thermal inputs may cause harm to a particular ecosystem, supplementary cooling equipment can be used.

New technologies will permit increase thermal efficiency of nuclear power plants and at the same time begin to put to use the low-grade waste heat that is now dissipated into the air and water. A population of 450,000 could enjoy year-round comfort conditioning with a 1000 megawatt nuclear plant providing electricity, heating and air conditioning (Simpson, 1972). To provide air conditioning in this manner, supplemental heat from the turbine cycle would be used to power a lithium-bormide air conditioning system.

Other possible uses of waste heat include secondary sewage treatment and agricultural applications to speed up or extend growing seasons.

Cost and Environmental Factors

The cost of protecting the environment must be factored in projections of future costs of electric power. During the 1960's, the electric utility industry accounted for an average of 14 per cent of all air pollutants discharged into the air. But the industry also purchased approximately 90 per cent of all the air pollution control equipment sold in the United States, spending between 1967 and 1971, about $1.6 billion on both air and water pollution control equipment (Simpson, 1972). Many more billions of dollars will have to be spent between now and 1975 to meet the tough new EPA regulations for air pollution discharges.

The increase in investment costs caused by pollution control regulations for fossil-fired plants in 1976 will be 7 per cent for gas, 26 per cent for oil, and 23 per cent for coal plants. Nuclear plants costs will be 5 per cent higher.

Base investment costs of a coal plant will rise from $110/kw of capacity in 1965 to $241/kw in 1975 because of inflation. Nuclear plant costs will almost double, rising from $155/kw to $306/kw. But when the costs of environmental protection are added, coal costs rise to $297/kw and nuclear to $321/kw in 1975. Environmental protection costs change the spread between nuclear fuel and cost from $65/kw to $24/kw in 1975 (Simpson, 1972). The lower cost of nuclear fuel more than offsets the capital costs differential between coal and nuclear.

LICENSING AND REGULATION

No one may build a nuclear power plant without receiving a construction permit and then an operating license from the United States Atomic Energy Commission.

The Atomic Energy Commission is an independent agency of the Federal Government headed by a five member commission appointed by the President (Forman, 1970).

To obtain a construction permit from the AEC, the applicant must submit his technical experience and financial responsibility. One of the requirements within the financial area is that the applicant must have a specified amount of insurance coverage against possible public liability. A typical new plant will carry about $600 million in insurance (Garvey, 1972). Figure 4 illustrates the time and reports required by the AEC of the Florida Power Corporation in order to construct and operate the nuclear power plant at Crystal River.

The United States Atomic Energy Commission (AEC) is required by the National Environmental Protection Agency (NEPA) to assess the potential environmental impact of any proposed nuclear power plant before issuing the applicant a construction permit for the plant (New Guidelines, 1972). In addition a more thorough assessment is made after construction is begun but before the operating license is issued. In each case the applicant is required to submit to the AEC an environmental report. In general, it contains (1) the environmental impact of the proposed action, (2) any adverse environmental effects which cannot be avoided,

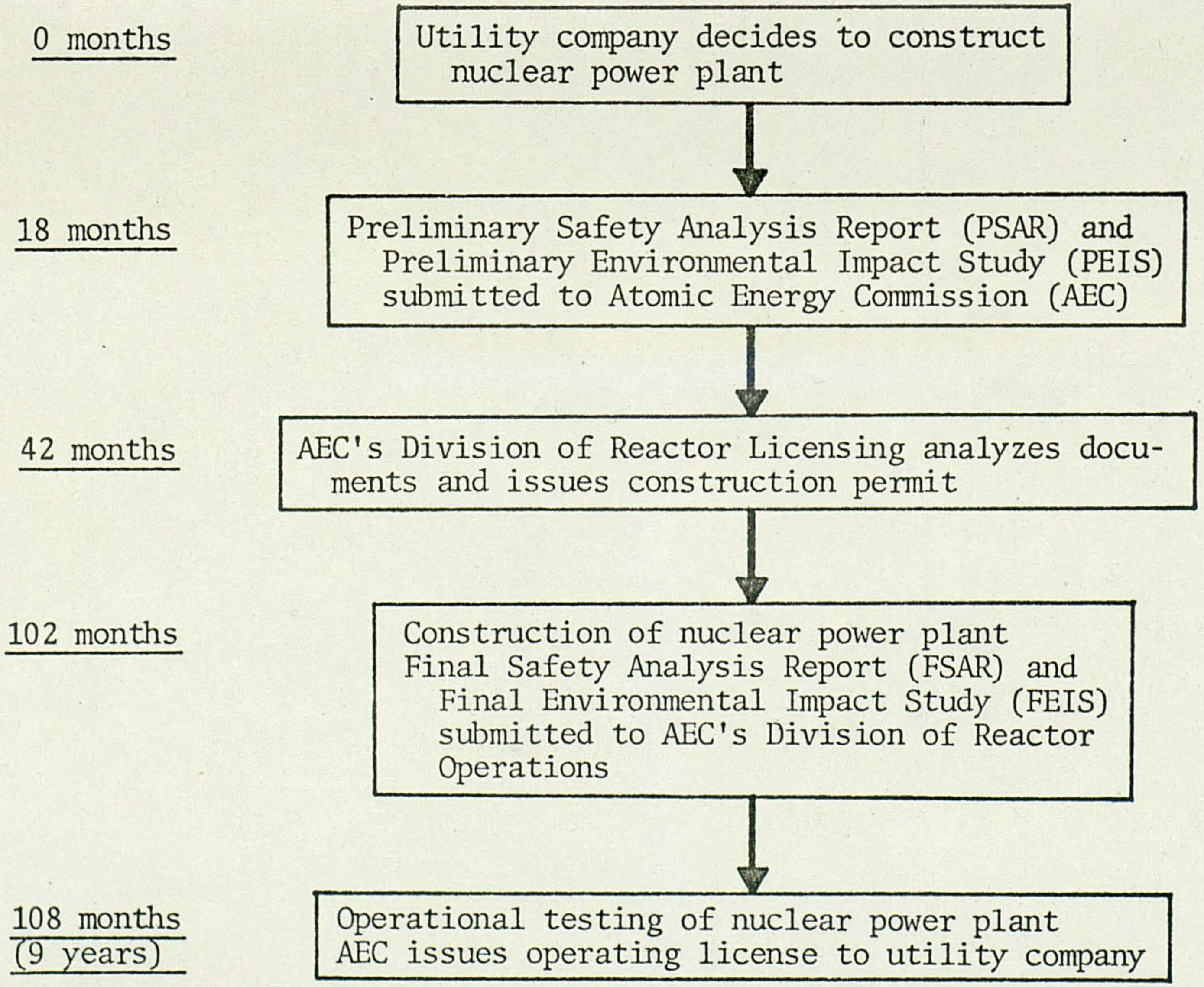

Figure 4. Flow Diagram of Licensing Procedure for the Nuclear Power Plant at Crystal River, Florida (Supplied by Mr. H. L. Bennett, Director of Generation Construction, Florida Power Corporation, Crystal River, Florida)

should the proposal be implemented, (3) alternatives to the proposed action, (4) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and (5) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented (Wilson, 1973).

THE SAFETY RECORD

Even though nuclear power generation is quite young in the United States, the amount of electricity that has been produced is already in the billions of kilowatt-hours.

During this time there has been no instance of radiation injury to any worker in nuclear power plants. The radiation exposure to the environment has been far below that allowed by the AEC regulations. The oldest plant in the country which has been in operation for 12 years has had no excessive release of radiation (American Broadcasting, 1973). There has been no instance of an accident of the type discussed earlier in this report.

The startup operation may extend over several months to a year or longer. Extensive check out procedures are instituted during this period. The plant is started at a very low level and then is increased to the full rated power of the plant. During this period the reactor usually experiences many automatic shut downs due to over sensitive control instruments or minor component failures.

In normal operation one factor is becoming quite important in relating nuclear power plants to that of fossil-fuel electric plants. The factor is that in nuclear plants the components that get the hardest wear are the reactor fuel elements. These elements are replaced when the plant is refueled at from one to two year periods. In fossil fuel plants the components that get the hardest wear are the tubes in the furnace section of the steam boiler, which of course are permanent type components. In time, these tubes present the most serious operation and maintenance problems of this type plant.

Recently, the AEC released a new all incompassing safety report which included discussion of regulatory processes, design of nuclear power plants, safety precautions, etc. The report stated the probability of a critical accident of any given nuclear power plant in any given year is one in a 1000. The AEC also projects approximately 1000 nuclear power plants operating by the year 2000. This then implies that there could be at least one accident per year. They state that an accident of this type would release no more than 10 curies of biologically harmful radioactive iodine, an amount asserted harmless to the surrounding population. They list the probability of the steel pressure vessel failing as one in a million (Gillette, January 1973).

CONCLUSIONS

The nuclear power plant of 1973 is a relatively inefficient way of generating electric power; its thermal efficiency is only about 32% and it does not utilize the fuel energy potential of uranium fuel. But in the context of the 1975 Environmental Protection Agency requirement, it is clearly head and shoulders above the fossil fuels because of its minimal effects on the environment.

The industry is now taking steps to provide for the very rapid and continuing growth of electric power and energy requirements and to do this in a manner that will provide acceptable environmental impact to the maximum extent for which the public is willing to pay the cost.

The need for power production is urgent and obvious. Planning or construction delays are unfortunate. An awareness and understanding of each party's problems and considerations are essential to constructive efforts to provide the necessary electrical power without destroying the world around us.

The environmental problems which exist

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