THE UNIVERSITY OF MICHIGAN

INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

DRESDEN NUCLEAR POWER STATION

Wayne Lowell Townsend

March, 1959

IP-363

TABLE OF CONTENTS

LIST OF FIGURES

1.0 FOREWORD

The Dresden Nuclear Power Station will be the largest, privately-financed, all-nuclear power plant in the United States. It is located 47 miles southwest of Chicago, at the junction of the Des Plaines and Kankakee Rivers. It is scheduled for regular operation in 1960, as a part of the Commonwealth Edison System.

The author worked at Dresden as an Engineering Aide for Bechtel Corporation, the engineering contractor, and wrote this paper after returning to study at the University of Michigan. His information comes from his own experience and the references listed in the Appendix.

2.0 INTRODUCTION

The Dresden Nuclear Power Station is a good example of one of the many peaceful uses of atomic energy. The station is being built as part of the "Independent Industrial Program" of the Atomic Energy Commission.[1] Dresden is unique among the many nuclear plants in the United States in that it will be the largest all-nuclear plant in the country, and is entirely financed by private industry through the Nuclear Power Group.[2]

Capacity of the plant will be 180,000 kw with a power factor of .85 at the generator terminals. Cost of the project will be $45,000,000 of which Commonwealth Edison, owner and operator of Dresden, is furnishing $30,000,000 and the other members of the Nuclear Power Group are furnishing the remaining $15,000,000. Commonwealth Edison is also spending $5,500,000 for administrative and site costs.[3]

The project was started in 1956, and at the time of the writing of this paper all the major buildings (Figure 1) have been completed.

A very interesting and outstanding feature of the Dresden plant will be the cost of the power produced. In present-day fossil fuel power plants, a very small fraction of the plant cost is devoted to research and development. At Dresden, however, a third of the total cost ($15,000,000) has been devoted to research and development.

---

1 James F. Fairman, Reference 1, pp. 95-6.

2 The members of the Nuclear Power Group are listed in the Appendix.

3 James F. Fairman, Reference 1.

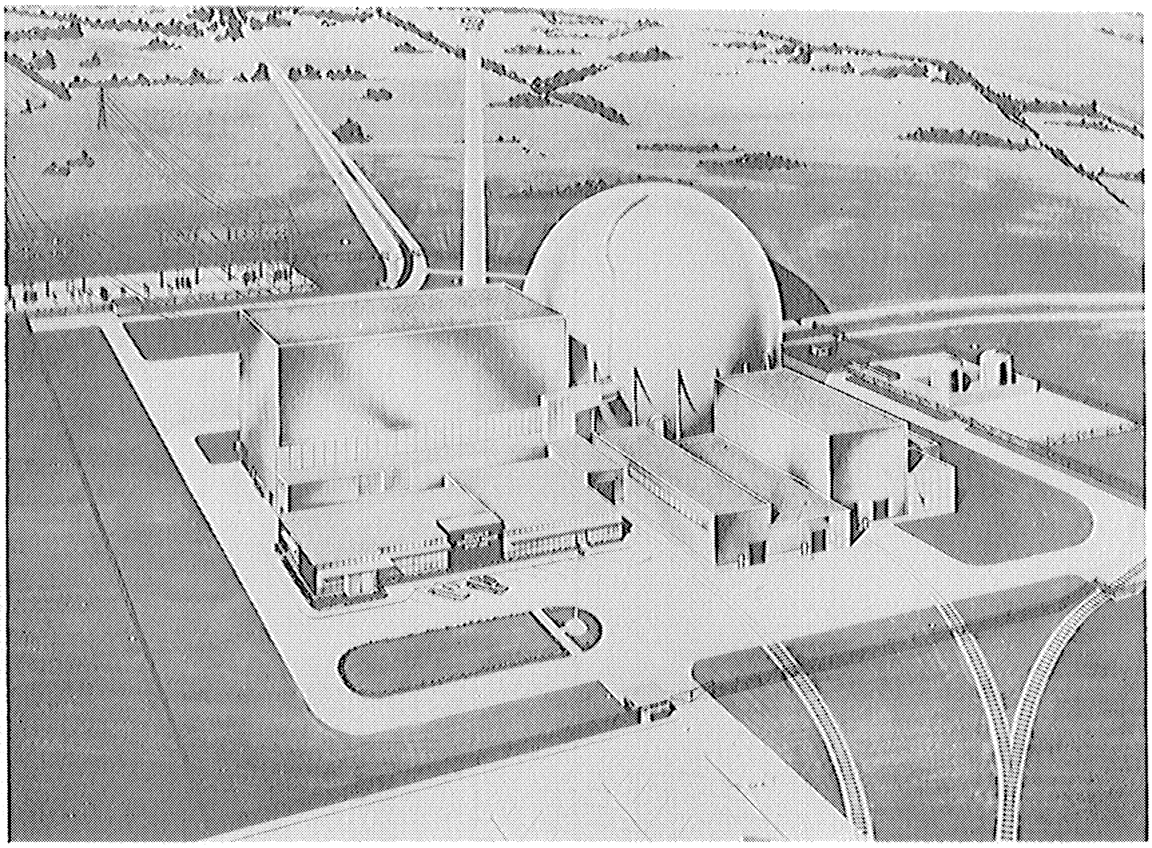

Figure 1. Artist's Concept of Dresden[4]

This cost will not be necessary if another plant of the Dresden type was built. Disregarding the cost of this research and development the plant cost is about $30,000,000. Using this figure as the total investment, Dresden will produce electricity for 3/4¢ per kwhr which is on a par with the most efficient fossil fuel plant in the Commonwealth Edison System.[5] For a region of high fuel cost, a nuclear power plant would produce electricity cheaper than a fossil fuel plant of the same size. In the future, as nuclear technology advances, it may well be that the fossil fuel power plant will become obsolete.

---

[4] Courtesy of Vaughn D. Nixon, Reference 2.

[5] James F. Fairman, Reference 1, pp. 95-6.

3.0 POWER CYCLE

The Dresden power cycle is shown in Figure 2. The process of energy conversion is the same as in a fossil fuel plant with one exception, the conventional boiler is replaced by a nuclear reactor. A nuclear reaction sustained in the reactor core at "A" in Figure 2 is cooled by boiling water giving the system the name "boiling water reactor." In the primary steam drum, the liquid water and steam are separated. The steam is sent by way of line "B" to the high pressure stage of the turbine. The flow of the primary steam is 1,400,000 lb/hr. This steam is saturated and at 1000 psig pressure. Liquid water at 1000 psig from the primary steam drum flows to the secondary steam generators, heats the secondary water at 500 psig, and then returns to the reactor via the demineralizer "C." The 500 psig water is sent to the secondary steam drum where the liquid and steam are separated. Secondary steam travels by way of the line "D" to an intermediate stage of the turbine where it combines with the primary steam which, by now, has been expanded to 500 psig in the turbine. The secondary flow is 1,190,000 lb/hr. After expansion in the turbine (which turns a generator) the steam is sent to the condenser. Liquid water (feed-water) from the

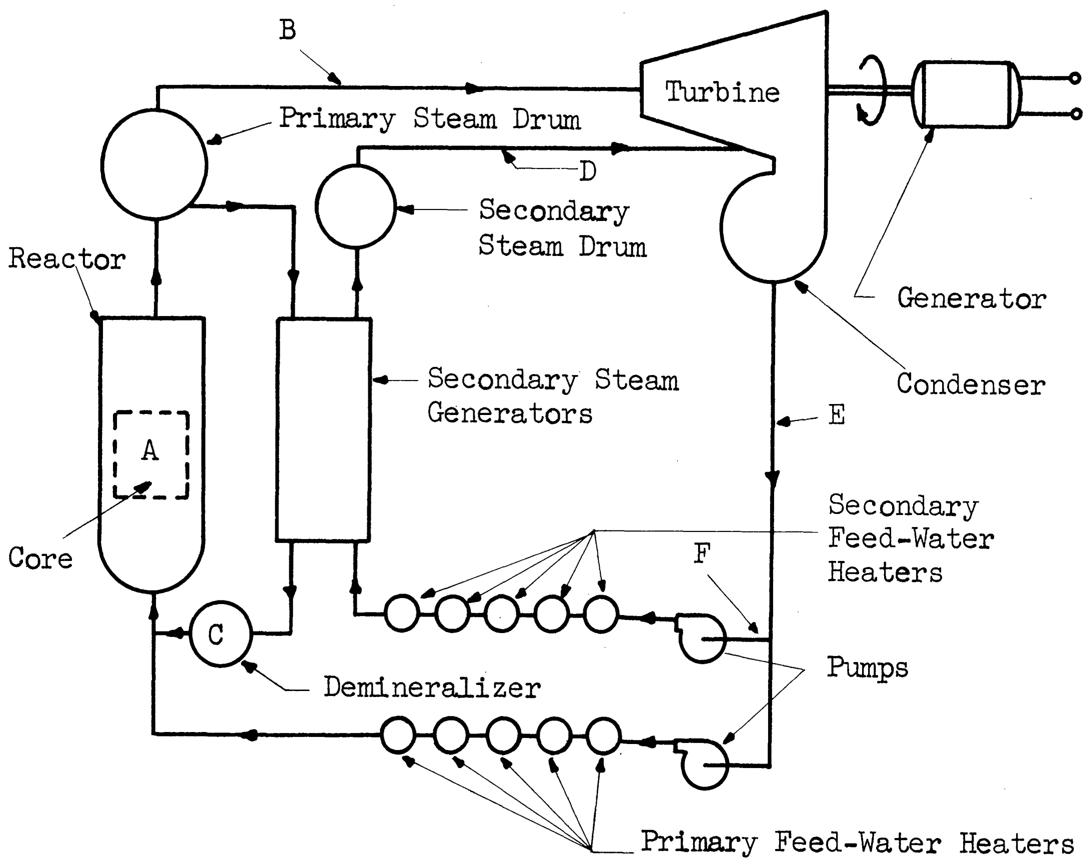

Figure 2. Dresden Power Cycle

condenser travels via line "E" to point "F" where 1,190,000 lb/hr goes into the secondary circuit and 1,400,000 lb/hr goes into the primary circuit. The feed-water is then pumped to 1000 psig and 500 psig in the primary and secondary feed-water pumps, respectively. After being brought to the desired pressure, the feed-water is heated in the feed-water heaters and recirculated through the power cycle.

4.0 EQUIPMENT

The equipment in the Dresden Nuclear Power Station will be discussed according to its place in the power cycle.

4.1 Reactor

The Dresden Reactor was designed using data from the Borax, Spert, Argonne, EBWR, and Vallacitos experimental boiling water

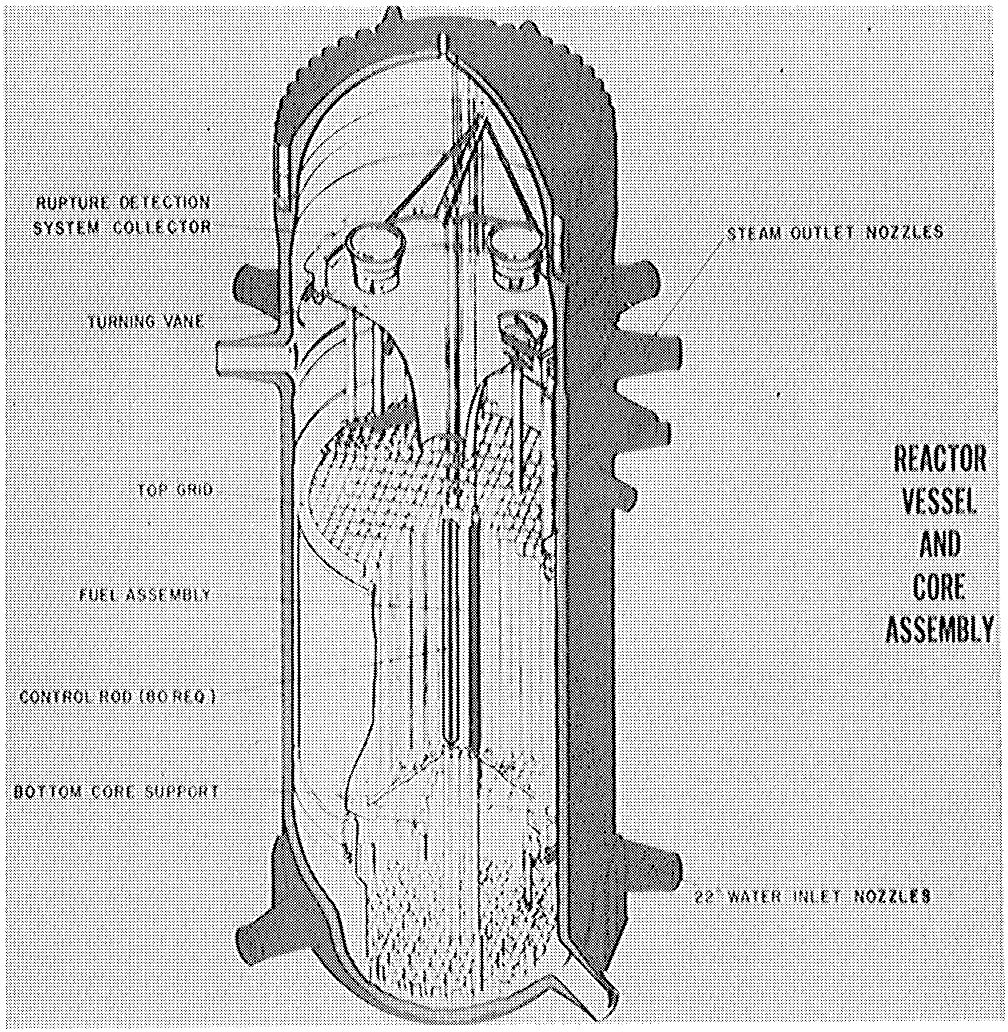

Figure 3. Reactor Vessel and Core Assembly[6]

---

6 Courtesy of Vaughn D. Nixon, Reference 2

reactors. It is housed in a 190-foot diameter sphere made of steel. The sphere is pressure tight to 39 psig. The reactor vessel and core are shown in Figure 3. The vessel is 40 feet high with an inside diameter of 12 feet, 2 inches.

4.1.1 Operation

Water enters the reactor from the bottom by way of the 22-inch inlet nozzles shown in Figure 3. The inlet velocity is 4.5 ft/sec, and the flow is upward at a rate of 25.6 million lb/hr. Orifices at the bottom of the vessel distribute the water evenly throughout the core. The inlet temperature of the water is 505°F, and the pressure is 1000 psig. As the water rises through the core, the temperature increases to 545.0°F (boiling point of water at 1000 psig) and boils to form a vapor-liquid mixture as the reactor outlet nozzles are reached. The velocity of liquid at the outlet nozzles is 9 ft/sec and that of the vapor is 12 ft/sec.

4.1.2 Core and Fuel

The reactor core weighs six tons, and contains a six-year supply of fuel. One ton of reactor core is equivalent in energy to 60,000 tons of coal.

Fuel is loaded into and taken out of the reactor core from the top by crane lift. The transport of the fuel to and from the reactor core is through a tunnel filled with water. Containers are provided for damaged fuel rods to prevent contamination of the water in the tunnel.

The fuel used at Dresden is uranium dioxide, slightly enriched. It is made as a sintered-solid-cylindrical pellet, 0.500 inches long and 0.493 inches in diameter. Series of pellets are encased in cylinders 28 inches in length with an outside diameter of 0.562 inches. Four cylinders are joined to form a 9-foot, 9-inch fuel rod. Each fuel rod fits into a fuel assembly containing 36 rods in square Zircaloy channels (Figure 5). The core contains 488 fuel assemblies and 80 control rods.

The control rods are made of stainless steel with 2.0% boron alloy as a nuclear poison. Their distribution is shown in Figure 6. Entering from the bottom of the reactor core, their upward movement decreases the nuclear reaction. The rods have a travel distance of 8 feet, 10 inches and an insertion speed of 6 inches/sec. In case of an emergency, all the control rods can be inserted in 2.5 seconds.

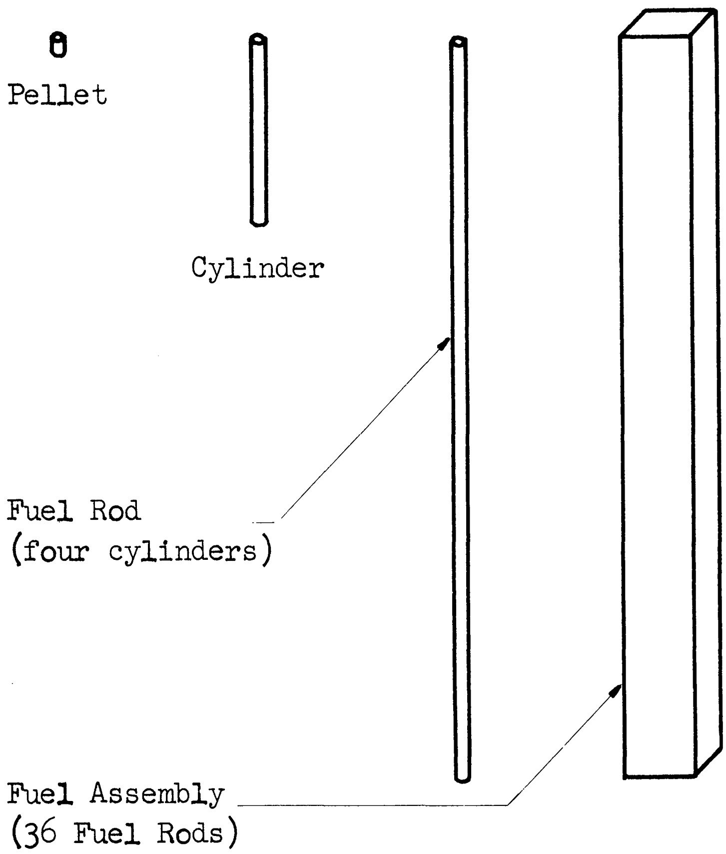

Figure 4. Construction of a Fuel Assembly

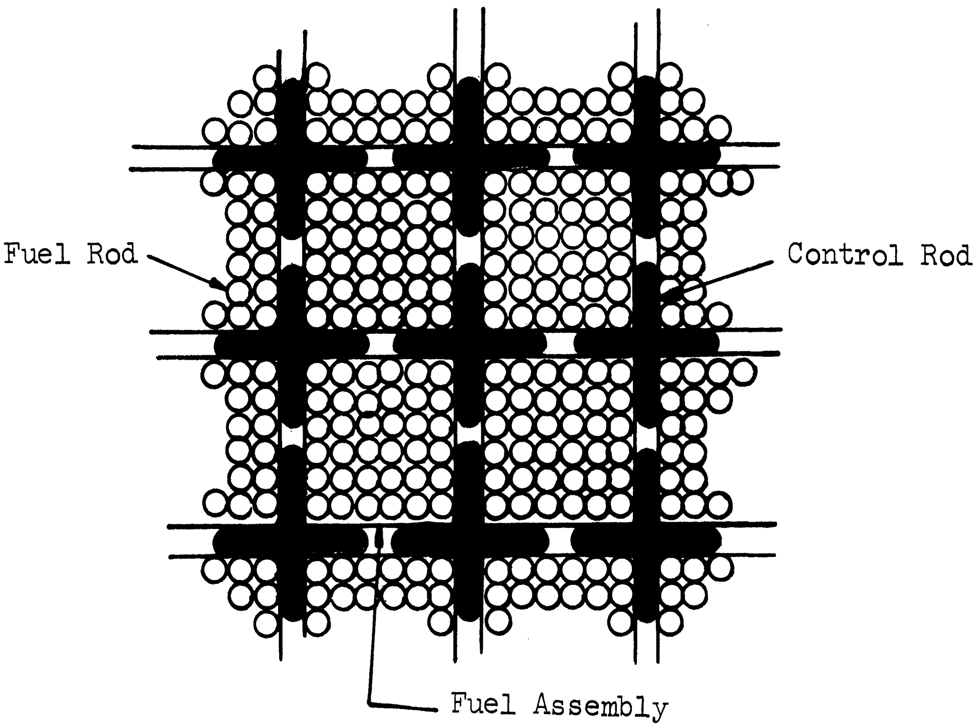

Figure 5. Reactor Core Cross-Section - Top View

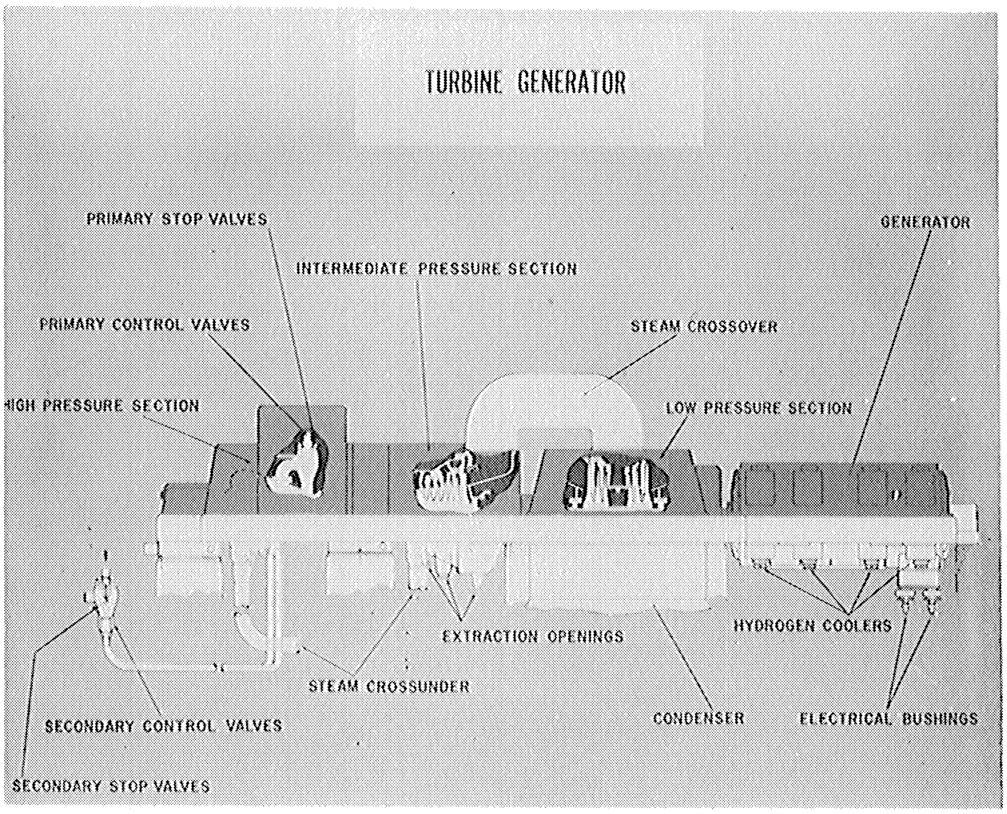

Figure 6. Turbine-Generator[7]

4.2 Primary Steam Drum

The primary steam drum has an inside diameter of 7 feet, 11 inches and is 67 feet in length. It produces steam with less than 0.1% moisture content. This is done with centrifugal type separators and chevron driers located in the drum. The pressure and temperature in the drum is 1000 psig and 545.0°F, respectively. The drum is made of steel.

4.3 Turbine-Generator

The turbine-generator set used in the Dresden Station is shown in Figure 6. The ratings are 200,000 kw, 1800 rpm, and 14,400 volts. Heavy shielding built around the equipment protects personnel from exposure to radiation.

---

[7] Courtesy of Vaughn D. Nixon, Reference 2.

4.4 Secondary Steam Generators

The secondary steam generators are large heat exchangers which take heat from the 1000 psig primary liquid water bleed from the primary steam drum, and transfer it to the 500 psig water in the secondary steam system. There are four secondary steam generators used at Dresden.

4.5 Condenser

The condenser is similar to that in a fossil fuel plant. Condensing rate is 2,590,000 lb/hr and the cooling is done by by water from the river. Average cooling temperature is 75°F giving an average vacuum of 13.825 psig.

4.6 Demineralizing Equipment

To minimize radiation transfer from the reactor to the other parts of the power cycle, extremely pure water is used at Dresden (600 parts per BILLION total impurities, and not more than 100 parts per BILLION of Chlorides).

4.7 Pumps

The feed-water pumps are supplied by the Pacific Pumps Inc. Three are used in the primary system and three in the secondary system. The personnel are shielded from the secondary pumps by heavy concrete walls.

4.8 Feed-Water Heaters

There are five feed-water heaters in both the primary and secondary loops. Their function is to raise the temperature of the feed-water to near the boiling point before it enters the reactor and the secondary steam generators. Steam is extracted from the turbine to supply the necessary heat.

5.0 RADIATION PROBLEM

Three types of major radiation are encountered in the Dresden Nuclear Power Station.

1. Neutron radiation from the fuel.
2. Gamma radiation from the fuel.
3. Radiation from nitrogen-16 created by neutron bombardment of the reactor cooling water.

The operating personnel are protected from neutron and gamma radiation by heavy concrete shieldings, some of which are ten feet thick. Nitrogen-16, however, is a gas and must be vented to a point where it can be irradiated. The reactor enclosure has a complete ventilating and storage system which removes 4,000 cubic feet of air per minute. After the proper length of storage time, the vented air is released to the atmosphere.

The Atomic Energy Commission has ruled that personnel cannot receive more than 100 milliroentgens effective mammal (mrem) per week, or approximately 2.5 mrem per hour if a man works a 40-hour week. At Dresden the radiation level runs from 0.5 mrem per hour, in uncontrolled access areas that are entered frequently, to a maximum of 12 mrem per hour in areas that are entered infrequently. With a proper work schedule personnel will not be exposed to a dangerous quantity of radiation.

The solid radioactive wastes in the form of spent fuel and blowdown from the secondary steam generators are stored under ground until they decay.

All the air used in the plant is routed from places of less radiation to places of more radiation.

The radiation problem at the Dresden Nuclear Power Station is minor. There is no danger to personnel unless an accident occurs, which is very unlikely, as will be seen in the next section on safety precautions.

6.0 SAFETY PRECAUTIONS

Of prime importance in the design of a nuclear power plant is safety. The designers of Dresden devised several devices to bring the reaction in the reactor core to a rapid halt in case an accident occurs.

The reactor can be shut down by rapidly inserting the control rods (a scram). The reactor can be scrammed in 2.5 seconds. If this fails, other alternatives may be used. A reactor poison can be dumped into the reactor. Sodium pentaborate ($Na_2B_{12}O_{16}10H_2O$) is used at Dresden. The boron in this compound is a neutron trap and breaks the chain reaction, thus ending the nuclear reaction. The boron concentration needed to poison the reactor is about 690 parts per million. About 400 pounds of sodium pentaborate are mixed with 580,000 pounds of cooling water and dumped into the reactor in 15 seconds. The nuclear poison reduces the neutrons radiated by about 20%k[8], and brings the chain reaction to a halt.

If the reaction in the core cannot be halted, a special cooling system is provided to carry away the heat of reaction.

An automatic scramming system is provided in case any of the following situations should occur:

1. if the pressure in the reactor enclosure exceeds atmospheric pressure by four inches of mercury,

2. if the pressure in the reactor vessel reaches 1050 psig,

3. if the heat flux in the core exceeds 120% of its maximum designed value, or

4. if the condenser vacuum falls to 23 inches of mercury.

It is not anticipated that there will be any problems of stability in the Dresden Reactor because of the following facts: (a) selection of a high operation pressure, (b) forced circulation of the system's cooling water (through the core), (c) relatively long fuel element time constant, (d) low ratio of reactivity of voids to void volume, and (e) close regulation of the reactor system pressure.

7.0 POTENTIAL OF THE PLANT

In the last few months General Electric Company, the prime contractor at Dresden, has collected significant information about UO_2 fuel, irradiation, critical assembly, heat transfer, and burnout. The Dresden core has been found to be sound over a considerable range, and has the capacity to increase the plant's capacity to 245,000 kw. Redesigning the core and adding superheating equipment fired by a fossil fuel would easily put Dresden in the neighborhood of 500,000 kw.

---

[8] k is a dimensionless constant which is a measure of neutrons liberated versus neutrons needed to continue the chain reaction. At Dresden, 18%k is sufficient to halt the reactor.

8.0 APPENDIX

8.1 Nuclear Power Group

1. American Gas and Electric Company
2. Illinois Power Company
3. Central Illinois Light Company
4. Kansas City Power and Light Company
5. Pacific Gas and Electric Company
6. Union Electric Company of Missouri
7. Bechtel Corporation
8. General Electric Company
9. Commonwealth Edison Company

8.2 References

1. Fairman, James F. "Nuclear Power Programs of Public Utilities in the U.S." Mechanical Engineering, 80, No. 11, November, 1958.

2. Nixon, Vaughn D. Review of the Dresden Nuclear Power Station. A paper presented to the Rocky Mountain Electric League, Denver, Colorado. April 14, 1958.

3. Dresden Nuclear Power Station. Commonwealth Edison Company, 1956.

4. Sisson, A. B., Reid, R. C., and Frazer, H. W. High Flow Rate Demineralization of Condensate for Boiling Water Reactor. A paper presented before the twentieth annual meeting of the American Power Conference. March 26-28, 1958.

5. Folsom, R. G. and Ohlgren, H. A. "Nuclear Engineering - Where Do We Stand?" Mechanical Engineering, 79, No. 3, March, 1957.