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U. S. GENERAL ACCOUNTING OFFICE

STAFF STUDY

LM097098

# SEQUOYAH NUCLEAR PLANT

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TENNESSEE VALLEY AUTHORITY

MARCH 1975

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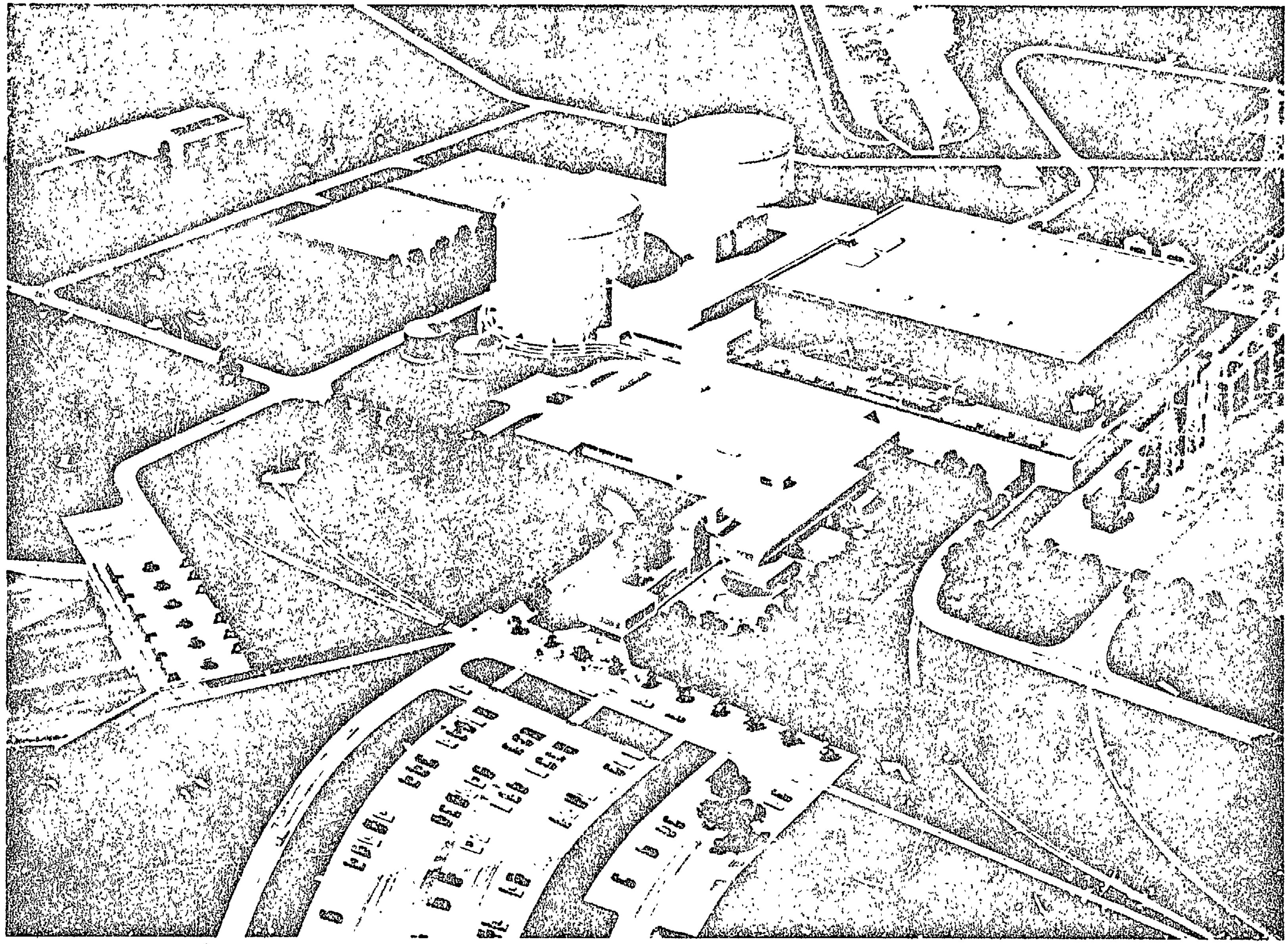




SEQUOYAH NUCLEAR PLANT - ARTIST'S CONCEPTION

# Contents



## ABBREVIATIONS

| | |
|---|---|
| EPA | Environmental Protection Agency |
| FSAR | Final Safety Analysis Report |
| KW | Kilowatt |
| NRC | Nuclear Regulatory Commission |
| PSAR | Preliminary Safety Analysis Report |
| TVA | Tennessee Valley Authority |
| UHI | Upper Head Injection |

## SUMMARY

Nuclear power plants are expected to supply an increasing share of the Nation's electricity for the remainder of the century, and to contribute toward the Federal goal of achieving energy self-sufficiency.

The Tennessee Valley Authority's (TVA) commitment to nuclear power is among the largest of any utility system in the Nation. The agency's studies indicate that nuclear plants represent the best short-range assurance of producing an adequate amount of electricity in an environmentally acceptable manner at affordable prices.

The Nuclear Regulatory Commission (NRC) [1/] and the Environmental Protection Agency (EPA) are the Federal regulatory agencies responsible for human and environmental safety of nuclear power plants. During the past few years, these agencies have issued many new guidelines and established new criteria to enhance safety.

Sequoyah is TVA's second nuclear power plant. The plant has two nuclear reactors and generating units with a combined gross electrical power output of over 2.4 million kilowatts. It is one of the first ice condenser containment type plants in the Nation. The ice condenser is a safety system that holds over 2.5 million pounds of small ice flakes. It is designed to rapidly quench heat and relieve pressure that could build up in the event of a reactor system rupture. Although the ice condenser had not been completely tested when TVA purchased it, TVA started plant design and construction concurrently to meet its power

1/ At the time our study was made, nuclear licensing and related regulatory functions were the responsibility of the Atomic Energy Commission. These responsibilities were subsequently transferred to NRC by the Energy Reorganization Act of 1974 (P.L. 93-438).

requirements forecast for the 1970's. The plant was about 65 percent complete as of September 1974.

PROJECT COST EXPERIENCE

TVA's initial cost estimate in 1968 for the Sequoyah plant was $336 million. As of September 1974, the estimate increased over 100 percent to $675 million -- a growth of $339 million. This cost growth is attributable to cost estimating, design and engineering changes during construction, inflation, higher interest on borrowed money than anticipated, and schedule delays.

The plant's commercial operation date has been delayed about 40 months from the initial plans, and TVA estimates it will incur additional costs of $317 million to obtain electricity from alternate sources during this intervening period. The needed electric power would have been provided by the Sequoyah plant had it been completed on schedule.

The cost increase of $339 million will cause TVA's power rates to increase about 2 percent over the plant's estimated commercial life of 40 years. The additional $317 million for alternate power sources will increase rates about 5 percent during the 40-month delay.

TVA prepared the initial cost estimate when the plant's design was less than 2 percent complete. Lack of experience in scheduling nuclear plant construction, and a new conceptual design--ice condenser--complicated the cost estimating process.

Costs rapidly increased as over 90 significant design and engineering changes were made during construction. New or modified NRC guidelines contributed to cost growth and schedule delays, and EPA requirements added to the plant's costs. Delays brought the project into a period of much greater inflation than envisioned in the initial cost estimate, and contributed substantially to higher interest costs.

The current cost will increase because of major items not included in the September 1974 estimate. NRC is still reviewing the project's final design, and further engineering changes may result in additional costs.

PROJECT SCHEDULE EXPERIENCE

TVA initially estimated commercial operation dates of October 1973 for Sequoyah's first reactor unit and April 1974 for the second reactor unit. These dates have now slipped about 40 months to January 1977 and September 1977. TVA even considers the current schedule to be optimistic.

The plant's delay is caused in part by TVA's optimism toward accommodating forecasted electric power requirements and not on a realistic assessment of the time needed for design and construction. TVA relied on inapplicable fossil-fueled plant construction schedules for guidance.

Evolving nuclear plant technology and changing NRC guidelines resulted in major design and engineering changes during construction which also caused schedule delay. NRC staff are now raising numerous questions about the plant's design, some of which could result in further plant modifications with associated schedule delays.

NRC data shows that about 10 years have been required to design and construct a nuclear power plant. The plants are often custom-designed making it necessary for NRC to extensively review each design and ensure that human and environmental safety standards are met. Each plant's site selection process also requires considerable time for collecting and evaluating environmental data prior to starting construction. NRC officials believe that standardizing plant design and selecting and approving plant sites well in advance of granting a construction permit are promising and practical ways of reducing plant lead time from 10 to about 6 years.

## PLANT PERFORMANCE

Sequoyah's power output will be only slightly reduced even though numerous engineering changes were made to the plant. The addition of cooling towers will cause the largest reduction.

One of the plant's major safety systems -- the ice condenser -- was undergoing test and analysis by the manufacturer -- Westinghouse Electric Corporation -- when plant construction started. As problems with this system were detected, major design changes were made and another safety system -- upper head injection -- was added. Other safety features were added or changed as NRC guidelines changed. Water temperature standards for the Tennessee River, which are now more strict than when TVA started its plant design, required constructing cooling towers and adding a new water pumping station.

As NRC completes its review of Sequoyah's design, other changes may become necessary, and the plant's operating capacity could possibly be restricted for safety reasons.

## COMING EVENTS

As construction continues, major coming events will include:

--NRC's completion of its review of TVA's final safety analysis report on Sequoyah. The purpose of this report is to support an application for an operating license.

--Review by the Advisory Committee on Reactor Safeguards. This Committee is an independent group established by law whose tasks include reviewing plant safety studies and license applications.

--Start of fuel loading and reactor testing in July 1976.

--Start of commercial operation in January 1977.

CONCLUSION AND RECOMMENDATION

Concurrent design and construction of nuclear plants is a normal industry practice according to NRC officials, and plants are often custom-designed making an extensive NRC review necessary to ensure public health and safety. As new technology is applied, NRC reviews become even more important. An extended period of time usually elapses between NRC's two-stage licensing review process -- 42 months in the case of TVA's Sequoyah plant -- and concurrency, customization, and new technology can increase the likelihood NRC will find problems with a utility's plant design. The result can be modified designs and backfits which translate into added costs and delayed schedules.

NRC officials acknowledged there was infrequent communication with utilities about specific plant designs and related problems during the interval between NRC's two-stage review. They informed us of ways utilities can stay informed of NRC requirements and acceptance criteria.

We believe it may be possible to reduce or avoid some modifications to nuclear plants if NRC maintained surveillance over critical features of a plant's design during the interval between its two regular reviews. Except for safety, the main concern should be to assist the utility in avoiding future increased costs and delayed schedules.

We recommend that NRC re-examine its licensing review procedures and practices with the objective of maintaining surveillance over nuclear plant designs during the interval between its two regular reviews -- particularly designs prepared concurrently with construction -- and of finding ways to provide concurrent assistance to utilities in order to reduce costs and maintain schedules.

MATTER FOR CONSIDERATION

Several bills were introduced in the 93rd Congress to help eliminate delays in the nuclear licensing process and to generally improve licensing procedures. Two features dealt with standardized nuclear plant designs and pre-selected nuclear plant sites. The latest bill to incorporate these features and to amend the Atomic Energy Act was H.R. 16700. Hearings were held but not completed.

The Congress may wish to continue reviewing the advantages and disadvantages associated with standardization and pre-selected plant sites, and consider appropriate legislation to help reduce nuclear plant lead time.

AGENCY COMMENTS

A draft of this study was furnished to TVA, NRC, and EPA officials, and their comments are incorporated as appropriate. As far as we know, there are no residual differences in fact.

QUESTIONS

Although not fully developed in this staff study, we believe there are some matters concerning this project which warrant further attention. The following questions are provided for use by the congressional committees during fiscal year 1976 hearings on the Tennessee Valley Authority and the Nuclear Regulatory Commission. These questions were included in the draft staff study sent to TVA and NRC for review, but we did not ask for a response.

Questions for TVA and NRC

1. NRC raised 427 questions during 1974 about the Sequoyah plant while reviewing TVA's final safety analysis report. What is the status of TVA's answers, and what will the realized or projected impact be on plant cost, schedule, and performance?

2. Westinghouse Electric Corporation is scheduled to complete tests on its redesigned ice condenser system in February 1975. What are the results of the tests to date, and will there be any impact on TVA's Sequoyah plant in terms of cost, schedule, and performance?

3. NRC has temporarily restricted the operating capacity of one utility company's ice condenser unit -- the Nation's first -- to 81 percent. TVA's Sequoyah plant will be the second nuclear plant with an ice condenser design. TVA is adding an upper head injection (UHI) system as an additional safety feature. NRC is reviewing UHI and expects to finish in June 1975. What are the results of NRC's review of UHI to date? Will UHI significantly increase the margin of safety expected? What is the likelihood that Sequoyah will not be allowed to operate at full power because of the ice condenser design?

Question for TVA

4. TVA is establishing a central cost data bank to help it more accurately estimate the cost of future nuclear power plants. A major construction cost element is the nuclear steam supply system (reactor, pressurizers, steam generator, ice condenser, and associated equipment) purchased from private manufacturers. TVA's contracts for these systems are awarded after advertising, and provide for payment on a fixed-price basis subject to escalation. Only the total purchase price is known. TVA does not have cost information on the major individual components of these systems because the contracts do not provide for access to contractors' records. Can TVA develop meaningful construction cost information for nuclear power plants lacking the major component costs of nuclear steam supply systems? Should this information be known in order to develop an adequate information base for future cost estimating purposes?

## CHAPTER 1

## INTRODUCTION

This staff study on the construction of TVA's Sequoyah nuclear power plant is part of the General Accounting Office's continuing effort to provide the Congress information on major acquisition programs of civil agencies. Although the Sequoyah project was about 65 percent complete as of September 1974, the study describes problems TVA encountered and makes suggestions for improvement in planning and constructing similar projects in the future.

### AUTHORITY, PURPOSE, AND SCOPE OF OPERATIONS

TVA is a corporation wholly-owned by the Federal Government. The agency was established by the Congress in 1933 to improve the public usefulness of the Tennessee River and to assist in the development of other resources of the Tennessee Valley and adjoining areas. The production and sale of electric power are part of TVA's resource development program.

In fiscal year 1974, TVA supplied electric power at wholesale prices to 160 municipal and cooperative electric systems which distributed power to more than 2.4 million customers in parts of seven states. TVA also served directly 47 industrial customers with large or unusal power requirements, and several Federal atomic, aerospace, and military installations.

### FINANCIAL ARRANGEMENT

TVA's electric power program is financially supported by power revenues and borrowings. The power program budget for fiscal year 1976 totaled over $2 billion.

TVA's Board of Directors are required by law to sell power at rates as low as feasible. However, these rates must provide gross revenues that will cover all costs associated with operating the power program including debt service (interest and principal payments on debts); payments to states and counties in lieu of taxes; dividend payments to the U.S. Treasury on the Federal Government's net appropriation investment in power facilities made in earlier years; repayments to the Treasury of the appropriation investment; and a margin for reinvestment in the power system. TVA considers 15 percent to be a desirable reinvestment margin even though this percentage has not yet been achieved.

The Congress has not appropriated funds to TVA for new power plant construction since 1953, but TVA is currently authorized by law to incur debts up to $5 billion for such purposes. As of August 31, 1974, TVA had outstanding debts totaling $2.8 billion which were incurred through bond and note sales, U. S. Treasury advances, and Federal Finance Bank loans. These debts are not obligations of or guaranteed by the Federal Government.

NUCLEAR POWER PLANTS

Nuclear power plants are expected to supply an increasing share of the Nation's electricity for the remainder of the century, and to contribute toward the Federal goal of achieving energy self-sufficiency.

TVA's current means of generating electricity is primarily from hydroelectric and coal-fired power plants. However, the agency's commitment to nuclear power is among the largest of any utility company in the Nation. Its studies indicate that nuclear plants represent the best short-range assurance of producing an adequate amount of electricity in an environmentally acceptable manner at affordable prices.

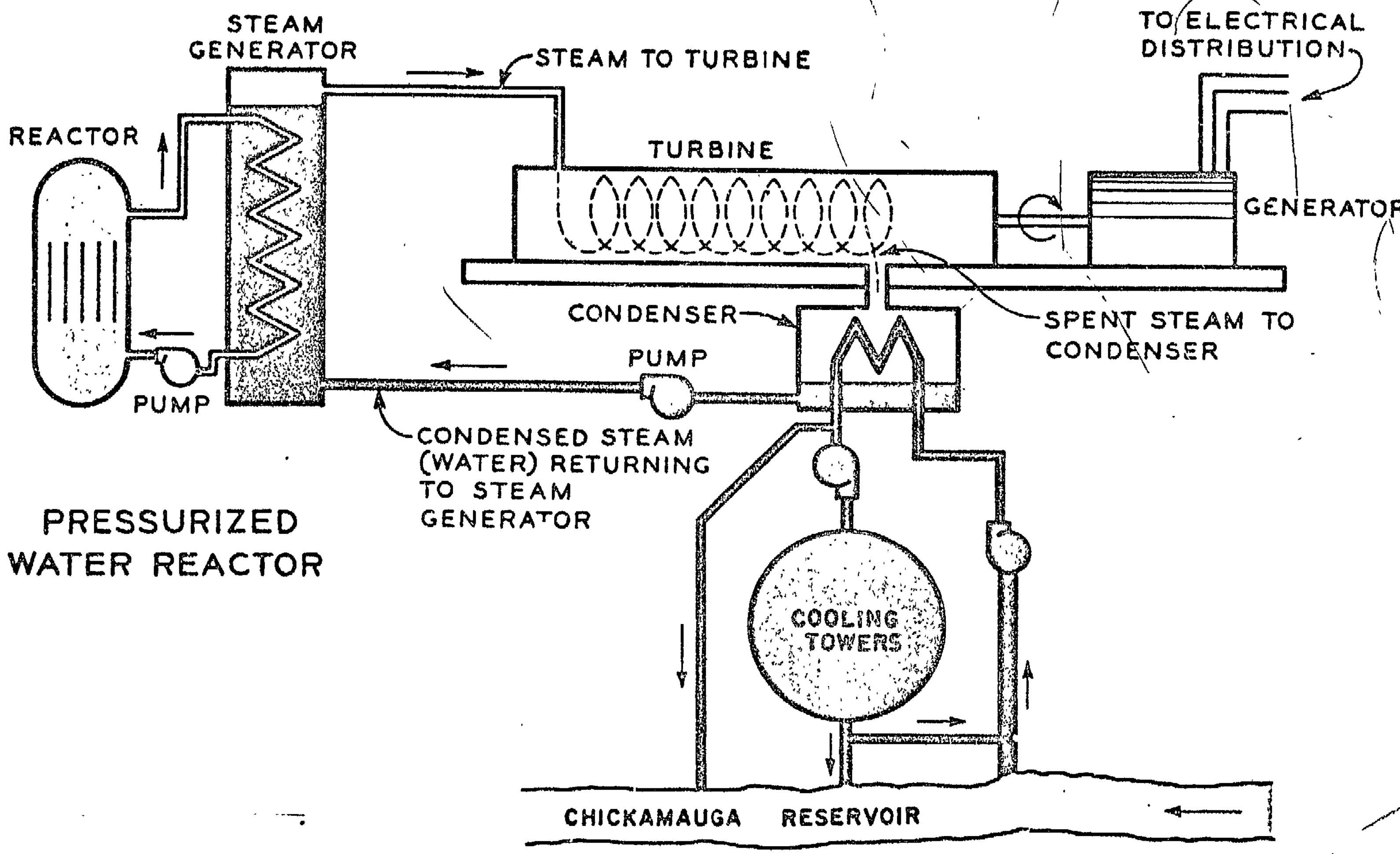
During the next 10 years TVA plans the most massive power plant construction program in its history, expanding current generating capacity from about 23 million kilowatts to 47 million kilowatts. TVA began constructing its first nuclear power plant--Browns Ferry--in 1966 near Decatur, Alabama. In 1969 preliminary construction began on the Sequoyah plant located northeast of Chattanooga, Tennessee. Construction started on a third plant--Watts Bar--in 1973 near Spring City, Tennessee, and a fourth plant -- Bellefonte -- in 1974 near Scottsboro, Alabama. Currently, three more nuclear plants are planned.

SEQUOYAH NUCLEAR
PLANT DESCRIPTION

TVA is its own architect, engineer, and constructor. For the Sequoyah plant, Westinghouse Electric Corporation is the major equipment manufacturer supplying the nuclear steam supply systems (reactors, pressurizers, steam generators, ice condensers and associated equipment) and the turbogenerators.

Sequoyah is a pressurized light water reactor plant, with two nuclear reactors and generating units having a combined gross electrical power output of 2,441,160 kilowatts.

The nuclear reactors are the source of heat for producing steam. The force of the expanding steam drives turbines that spin a rotor inside a magnetic field to generate electric power (see Figure 1). Controlled nuclear fission of uranium fuel will create the heat in a pressurized reactor core. The reactor core contains more than 50,000 long, slender




BEST DOCUMENT AVAILABLE

FIGURE 1

fuel rods which hold 111 tons of uranium dioxide--about one-third of which are replaced each year.

The plant is designed with three separate and distinct water cycles for each nuclear steam supply system (see Figure 1). The first cycle consists of pressurized water circulating upward through the reactor core to transfer the heat generated by nuclear fission. The heated water is pumped to a steam generator where it passes through U-shaped tubes. The second cycle contains water surrounding these heated tubes. The water absorbs the heat and is turned to steam. The steam turns a turbine generator to produce the electricity. The steam continues through the turbines to a condenser that converts the steam back to water by circulating it around tubes cooled by a third cycle of water pumped from a reservoir in the Chickamauga Lake. The water collected from condensed steam in the second cycle is then pumped back to the steam generator to continue the steam-making process. The lake water flowing through the plant's condensers never enters the steam generator or the reactor vessel, but either (1) flows through cooling towers and returns to the lake, (2) flows through the cooling towers into the water intake channel and is pumped back through the condensers in a closed-loop cycle, or (3) is discharged directly to the lake.

Sequoyah is among the first nuclear power plants to use a new type of reactor containment vessel which includes an ice condenser (see Figure 2). Other nuclear power plants that do not have ice condensers house the nuclear reactor in a large steel or steel-lined concrete vessel. Because of the

## SEQUOYAH REACTOR BUILDING

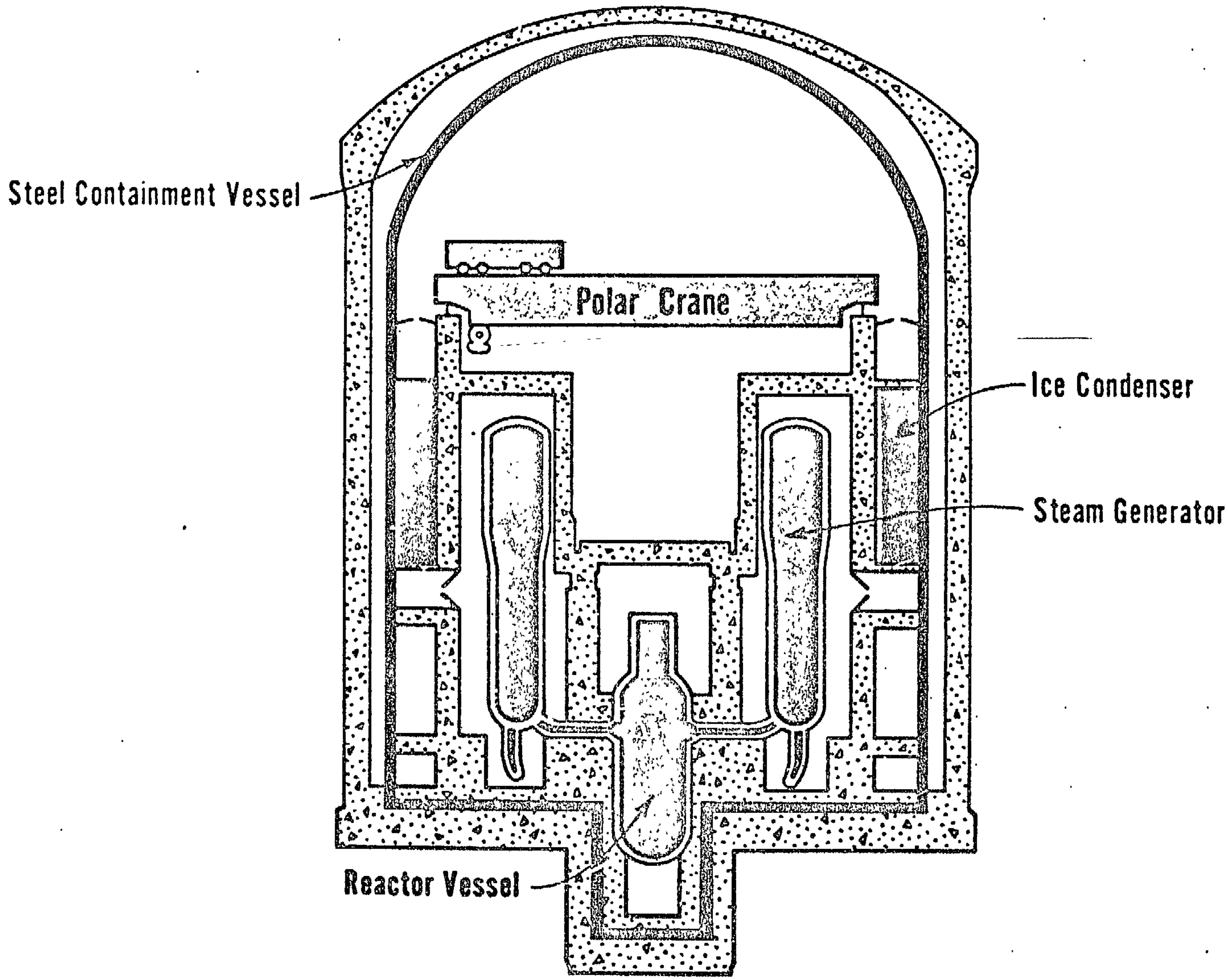



FIGURE 2

ice condenser, Sequoyah's two steel containment vessels are considerably smaller and each are enclosed by a 3-foot thick reinforced concrete wall. The concrete building serves as a biological shield as well as structural protection for the steel vessels.

The steel vessels contain an annular chamber 13 feet wide that will hold over 2.5 million pounds of small ice flakes. In the event of a reactor accident, the mass of ice is expected to rapidly quench heat and pressure that might occur within the containment vessel.

Other primary safety systems in the containment area, but not pictured, include an emergency core cooling system and a containment spray system.

SCOPE OF STUDY

This study covers the project's status as of September 1974 in terms of cost, schedule, and technical performance. It also identifies the changes and the basic reasons for them since the project was presented to the Congress in January 1969.

We obtained the information by interviewing TVA, NRC, EPA, Westinghouse Electric Corporation, and State of Tennessee officials; and by reviewing pertinent Federal and state laws and regulations, and agency files and correspondence.

We performed the study at TVA offices in Knoxville and Chattanooga, Tennessee; the Sequoyah project site near Daisy, Tennessee; the NRC office in Bethesda, Maryland; and the EPA regional office in Atlanta, Georgia.

## CHAPTER 2

## PROJECT COST EXPERIENCE

TVA's initial cost estimate of $336 million in August 1968 for the Sequoyah plant increased by $339 million or over 100 percent to $675 million as of September 1974. The cost growth is attributable to cost estimating, design and engineering changes during construction, inflation, higher interest on borrowed money than anticipated, and schedule delays.

TVA officials estimated that additional costs of at least $317 million will be incurred to obtain needed electricity from alternate sources because the plant was not completed on schedule. These costs are in addition to the estimated operating costs TVA would have incurred if the Sequoyah plant had started producing power when originally planned. The alternate electricity needed during the schedule delay period is provided by continuing usage of less economical fossil-fueled plants, using newly acquired combustion turbine power generators, and purchasing power from other utility companies.

TVA may incur even more costs as a result of continuing NRC and EPA reviews of the plant's safety and environmental features. Ultimately, all costs are passed on to TVA customers.

Table 1 compares the initial construction cost estimates with current estimates.

Table 1

| Cost categories | Estimated project costs (Millions) August 1968 | Sept.1974 | Dollar increase | Percentage increase |
|---|---|---|---|---|
| Construction labor | $ 48 | $112 | $ 64 | 133 |
| Material, equipment, and subcontractor | 203 | 307 | 104 | 51 |
| General expense including design | 32 | 95 | 63 | 197 |
| Contingency | 17 | 19 | 2 | 12 |
| Interest during construction | 36 | 142 | 106 | 294 |
| Total plant construction cost | $336 | $675 | $339 | 101 |
| Nuclear fuel | 54[a] | 78[a] | 24 | 44 |
| Plant construction cost including nuclear fuel | $390 | $753 | $363 | 93 |

[a]TVA does not include initial fuel costs in construction costs, although both are capitalized.

COST ESTIMATING

TVA's initial cost estimate was understated primarily because TVA lacked experience in scheduling construction of nuclear power plants, and could not anticipate the number of engineering changes or the extent of inflation.

Other power companies also had estimating problems. For example, Power Engineering, a power generation engineering magazine reported in August 1974:

> "There was not much experience in the mid-1960s with nuclear power plant capital costs, and the estimates made at that time for future plants are turning out to be far too low. In aggregate, the true cost of the 29 nuclear plants contracted for in 1965-66 probably will reach more than double the aggregate of the original estimates."

NRC data published in the same issue further illustrated increasing construction costs. The data showed that 30 nuclear plants contracted for in 1967 will have an average cost of $354 a kilowatt (KW) compared to original estimates of $146/KW and 14 nuclear plants contracted for in 1968 will average about $413/KW compared to original estimates of $157/KW for 17 plants. Sequoyah is currently expected to cost $276/KW compared to an original estimate of $138/KW.

The Sequoyah plant's design was less than 2 percent complete when the original cost estimate was made. Construction labor hours nearly doubled to 15.4 million hours from the original estimate of 8.2 million. Engineering design costs (which also represent labor hours) were three times larger than the original estimate--$45 million compared to $15 million.

TVA officials informed us that because of limited experience in scheduling nuclear plant construction, initial labor hour estimates were understated. TVA recognized this underestimate early in the program, and in January 1970 increased the original estimate from 8.2 million to 12.2 million hours. Labor hours were later increased because of design and engineering changes during construction, and because formal quality assurance procedures were implemented.

## DESIGN AND ENGINEERING CHANGES DURING CONSTRUCTION

During construction, design and engineering changes probably had more impact on cost growth than any other single factor. These changes affected all areas--labor, material, interest, and schedule--and primarily resulted from TVA initiated design changes, NRC and EPA requirements for added nuclear safeguards and environmental protection, and equipment manufacturers' redesigns.

To illustrate this problem, TVA identified over 90 significant engineering changes that were made to Sequoyah after the original cost estimate. These changes were attributed to: NRC requirements - 35; TVA redesigns - 28; TVA decisions because of improved technology or cost savings - 13; EPA requirements - 4; equipment manufacturers' redesigns - 4; equipment manufacturer modifications because of safety criteria changes - 4; and other requirements - 5. Selected major changes are discussed in the Plant Performance section of this staff study.

INFLATION

TVA officials attributed about $150 million or 22 percent of the $675 million project cost to inflation. The original cost estimate included an allowance for inflation, but the inflation rate experienced was much greater than anticipated.

TVA's original and current projections of annual inflation percentage increases for labor, material, and interest rates are shown in Table 2.

Table 2

| Cost category | Annual percentage projections August 1968 | September 1974 |
|---|---|---|
| Labor rates | 4 | 10 |
| Material | 3 | 10 |
| Primary equipment manufacturer | | |
| Material | 2 | 21.1[a] |
| Labor | 5.5 | |
| Interest | 6 | 8.5 |

[a]Cumulative actual rate based on escalation clause in contract.

In 1968, TVA's nuclear plant construction employees averaged $4.65 an hour including fringe benefits. The agency initially estimated that the labor rate for the Sequoyah plant would average $5.86 an hour over the project's construction period. The current estimate averages $7.29 an hour--a 24 percent increase.

Material costs increased considerably during Sequoyah's construction period. Table 3 shows material price escalation before and after the project started.

Table 3

| Material category | Total percent of escalation for periods 1964-1968 | 1969-1973 |
|---|---|---|
| Iron and steel | 6 | 37 |
| Steel mill products | 6 | 30 |
| Alloy steel bars | 11 | 28 |
| Nickel cathode sheets | 19 | 49 |
| Electrical sheet alloy | 7 | 26 |
| Copper wire | 41 | 45 |

TVA officials stated that their fixed price contract policy and Federal wage and price controls reduced the full impact of inflation during the early part of construction, but later material costs increased rapidly.

Interest rates fluctuated during the construction period but were generally higher than the 6 percent rate TVA initially projected. The effect of higher rates was estimated at $13.5 million. Table 4 shows the average rates incurred or projected by fiscal year. Increased interest costs that are not related to higher rates are discussed in the next section.

Table 4

| Fiscal year | Incurred or projected interest rate |
|---|---|
| 1970 | 7.3 |
| 1971 | 8.0 |
| 1972 | 5.5 |
| 1973 | 6.0 |
| 1974 | 7.0 |
| 1975 | 8.5[a] |
| 1976 | 8.5[a] |

[a] Projected

INTEREST ON BORROWED MONEY

TVA officials estimate a $106 million interest cost increase over the $36 million initially projected bringing the total to $142 million. Approximately $79 million of this increase is attributable to construction schedule delays requiring larger borrowings and therefore more capitalized interest. About $13.5 million is attributable to higher capital costs of the plant also requiring greater borrowing. The remaining $13.5 increase was due to higher interest rates as discussed above.

TVA capitalizes interest costs during construction, and these costs are charged to operating expenses when the plant begins commercial operation. As of June 30, 1974, $51 million were capitalized. At project completion, assuming the current project cost estimate is not increased, interest costs would be charged to operations at the rate of about $5 million a month. This includes not only all accumulated capitalized interest, but also interest incurred on other debts required to pay the capitalized interest.

## OTHER COSTS

TVA officials estimated that additional costs of at least $317 million will be incurred other than those attributable to project cost growth, because Sequoyah's construction was not completed on schedule. To satisfy its customers' electricity needs during the approximately 40-month delay period, TVA must obtain power from alternate sources by making greater use of less economical fossil-fueled plants, using 20 newly acquired combustion turbine power generators, and purchasing power from other utility companies.

The extra costs are in addition to the estimated operating costs TVA would have incurred if the Sequoyah plant had been operable as originally planned. A major portion of these added costs is due to the more expensive type of fuel that will be used. For example, in the first quarter of fiscal year 1975, TVA's cost to produce 1,000 kilowatt hours using nuclear fuel was $1.55 as compared to $4.58 for coal and $25.53 for fuel oil.

Installation of the 20 combustion turbines are estimated to cost $137 million. TVA officials stated that the turbines were purchased specifically because Sequoyah was not placed in commercial operation as planned. They added, however, that the turbines may be used in later years to meet peak and emergency electricity requirements. A portion of the turbines depreciable costs were included in the estimated $317 million discussed above.

## HIGHER POWER RATES TO CONSUMERS

TVA estimates power rates charged its customers will increase about 2 percent during Sequoyah's estimated commercial life of 40 years because of the $339 million cost growth. A rate increase of about 5 percent will be needed during the 40-month period the plant's schedule was delayed to pay the $317 million for the alternate sources of power discussed above.

TVA officials expect nuclear power plant construction costs to continue increasing and these costs will be passed on to consumers. In 1983, TVA estimates it gross kilowatt capital cost to be about $650. This compares to Sequoyah's current estimate of $276 per gross kilowatt. Construction costs for other methods of producing power also will be higher.

# CHAPTER 3

## PROJECT SCHEDULE EXPERIENCE

The first reactor unit was originally scheduled for commercial operation in October 1973, and the second unit in April 1974. The latest estimate is January 1977 and September 1977 which represents a delay of about 40 months from the initial plan.

The principal causes of the delay were TVA's optimism toward accommodating forecasted electric power requirements; TVA's reliance on inapplicable fossil-fueled power plant construction schedules for guidance; and NRC's licensing review practices and required modifications.

Selected specific problems contributing to the delay included:

--Additional material testing and documentation because NRC altered its quality assurance requirements;

--Modified NRC criteria resulting in redesign and some backfitting of nuclear pipe systems to protect against a pipe-rupture;

--TVA analysis and redesign for altered pipe-rupture criteria resulting in postponing orders for material that eventually caused late delivery;

--Dismantling other completed structures because of altered design criteria;

--A new and untested ice condenser system that later proved unacceptable requiring extensive redesign; and

--Changes to the emergency core cooling system.

TVA is not the only utility experiencing schedule delays--the problem is industry-wide. For example, the Atomic Industrial Forum--a not-for-profit international management association representing more than 600 organizations interested in the peaceful uses of nuclear energy--published a report in April 1974 on the causes of nuclear power plant delays. The report concludes that 46 of 47 nuclear plants under construction experienced schedule delays ranging from 5 to 61 months. Although several delay factors are listed, the major causes and related percentages of delayed plant months are as follows: changes imposed by modifications in licensing and regulatory requirements (42%); shortages and inadequate productivity of personnel (17%); and late delivery of components and/or materials (8%). Other delays were caused by administrative or legal procedures, action by interveners commercial considerations, and site-related problems.

## OPTIMISTIC SCHEDULING AND NUCLEAR PLANT INEXPERIENCE

TVA officials told us, and the documents we reviewed indicated that Sequoyah's schedule was optimistic. A major reason was because key schedule dates were based on projected operational dates when Sequoyah's electric power would be needed. Thus, TVA force-fitted the design and construction schedule to accommodate electric power requirements, and did not base the operational date on a realistic assessment of the time needed for design and construction.

Because TVA's experience in scheduling nuclear plant design and construction was limited, the agency relied upon its extensive fossil-fueled plant experience to help establish Sequoyah's schedule. TVA later learned that fossil power plant construction methodology is not fully applicable to nuclear power plant construction.

Sequoyah's latest projected commercial operating dates in 1977 may also be optimistic because of future uncertainties associated with material delivery dates, ice condenser system test results, and NRC requirements. The latest projection contains no allowance for additional changes that may be made by the primary equipment manufacturer or for compliance with additional NRC requirements.

NRC IMPACT ON SCHEDULE

TVA officials asserted that NRC has had a major impact on Sequoyah's schedule by issuing several new industry-wide regulatory guidelines. NRC's primary concern is to ensure that nuclear plants are designed and constructed to operate safely, and little consideration is given to the effect of these guidelines on delaying schedules. Delays translate into higher capital costs.

NRC officials said the period of 1968 through 1974 was a time of great evolution for nuclear regulatory requirements. When TVA started designing Sequoyah in 1968, nuclear safety criteria were broad and general. Since then, NRC has formulated and continued to upgrade its regulatory guides to provide more detailed guidance on what is acceptable. NRC officials acknowledged that this caused schedule delays because applicants could not foresee these changes during a plant's early design stages.

Although applicants are not legally required to comply with NRC regulatory guides, they usually update their designs to conform with NRC's latest guides or interpretations. NRC officials told us that applicants would rather not take a chance of not being granted an operating license because of noncompliance. TVA officials stated that their experience indicates that NRC guidelines are used in practice in nearly every case as if they had the force of law with NRC's leverage residing in the threat of "no compliance, no operating license."

Backfitting

TVA officials informed us of 23 cases at the Sequoyah project where a structure or component had to be torn out and rebuilt, or added because of required changes. Backfittings for which NRC was responsible were due to issuing industry-wide regulatory guidelines. Table 5 below shows the number of backfitting cases and the organization responsible for causing the change.

Table 5

| Project impact[1/] | Organization responsible | | | | |
|---|---|---|---|---|---|
| | NRC | TVA | EPA | Equipment manufacture | Total |
| Major | 6 | 1 | 2 | 2 | 11 |
| Minor | 3 | 5 | 2 | 2 | 12 |
| Total | 9 | 6 | 4 | 4 | 23 |

1/Major impact includes changes that cost $2 million or more.
Minor impact includes changes that cost less than $2 million.

TVA officials stated that NRC seldom reviews backfits to assure that substantial benefits are derived, and believe NRC should justify any major change after issuing a construction permit. Because the backfittings for which NRC was responsible were the result of issuing regulatory guidelines to all utilities, no cost-benefit analyses were made for specific plants affected.

NRC Licensing Review

NRC regulations require a two-stage licensing review process before issuing a nuclear plant operating license. The first review is based upon an applicant's Preliminary Safety Analysis Report (PSAR) in support of a construction permit application. The second review is based upon the applicant's Final Safety Analysis Report (FSAR) in support of an operating license application.

NRC approved TVA's PSAR which presents general design criteria and preliminary design information, and issued a construction permit on May 27, 1970. In December 1973, TVA submitted its FSAR to NRC which provides details on the plant's final design. NRC and TVA officials acknowledge that during this 42-month period there was little communication between the agencies specifically related to Sequoyah's design and construction. In fact, NRC informed us that relatively speaking this is true for all applicants. As a consequence, NRC had little knowledge of Sequoyah's design details until it reviewed the FSAR at which time the plant was about 60 percent complete, and the plant's design was nearly complete. As the NRC staff reviewed the FSAR during 1974, 427 questions were generated about the plant. The resolution of some of these questions could result in further plant modifications.

For example, with NRC approval, TVA designed Sequoyah's reactor buildings to withstand the impact of tornado-hurled objects such as:

--a cross-tie, 7 inches by 9 inches by 12 feet long,

--a steel pipe 2 inches in diameter by 7 feet long, and

--an automobile 4,000 pounds traveling at 50 miles an hour at a maximum height of 25 feet.

In June and October 1974, NRC asked TVA to analyze the impact of additional objects such as:

--a steel pipe 12 inches in diameter by 15 feet long,

--a steel rod 1 inch in diameter by 3 feet long,

--a utility pole 13 $\frac{1}{2}$ inches in diameter by 35 feet long, and

--a 4,000 pound automobile hitting the top of the reactor building which is 151 feet high.

TVA officials believe there is no new evidence to show that either set of objects ~~is more~~ realistic than the other, and consider NRC's request to be an academic exercise. NRC officials informed us that a preliminary review of TVA's responses indicates that the reactor buildings will not require reinforcement, but that some plant features are not protected by buildings and may require plant additions.

POTENTIAL FOR REDUCING
NUCLEAR PLANT LEAD TIME

NRC has recommended standardizing nuclear plant designs as one aid toward simplifying and shortening its licensing review process. NRC believes as industry gains experience in duplicating major portions of standardized plants, construction time and costs could also be reduced. NRC perceives standardization as a long-term goal, but estimates that the 10 years it has taken to construct a nuclear plant could be reduced about 2 years by common plant design.

TVA supports plant standardization and is implementing the idea for a new nuclear plant scheduled for completion in 1980-1982. However, agency officials informed us that no appreciable licensing schedule advantage has been granted to date.

NRC and TVA officials agreed that pre-selected nuclear plant sites would also reduce a nuclear plant's lead time by 1 to 2 years. The beginning of plant construction would not be delayed if an applicant completed the site environmental reports, held public hearings, and secured NRC approval on a predesignated plant site years before plant design started.

Several bills to amend the Atomic Energy Act were introduced in the 93rd Congress to help eliminate delays in NRC's nuclear licensing process and generally improve licensing procedures. Two features included in these bills dealt with standardized nuclear plant designs and pre-selected nuclear plant sites. The latest bill--HR. 16700--incorporated these features and hearings were held but not completed. NRC considers these two approaches to be a practical way to help reduce nuclear plant lead time from 10 to about 6 years.

# CHAPTER 4

## PLANT PERFORMANCE

The Sequoyah plant's proposed gross electrical power output is designed at 2,441,160 kilowatts. About 6.5 percent of this output was designed as station use power allowing the remaining net power output of 2,280,000 kilowatts to be distributed commercially. Although numerous engineering changes were made to the plant, net power output will be only slightly reduced. The addition of cooling towers will cause the largest reduction. However, future NRC decisions could further limit Sequoyah's power production.

Major problems that TVA has encountered at Sequoyah are discussed below.

### ICE CONDENSER

The ice condenser is an enclosed refrigerated compartment circling most of the inside of the steel containment vessel (see Figure 2). In 1968, TVA purchased the ice condenser system design for Sequoyah from Westinghouse Electric Corporation. The design had not been tested, but it was less expensive than other designs and had more safety features.

NRC approved the system's operational theory, but stated that further testing was needed. In the early construction stages, TVA discovered that the design failed to consider certain non-uniform pressures which could cause the containment vessel to buckle.

In February 1972, TVA added steel stiffeners to the vessel that provide additional pressure safety margins to resolve the potential buckling problem. Later in 1972, contractor tests of the ice condenser system disclosed a need for further design modification. The contractor's records showed that redesign was completed in September 1974 and testing was expected to be completed in February 1975. Both TVA and design contractor officials have confidence in the new design.

TVA officials attribute a significant portion of the project's delay to the addition of steel stiffeners and ice condenser redesign.

UPPER HEAD INJECTION SYSTEM

Upper head injection (UHI) is part of the nuclear reactor's emergency core cooling system. UHI helps cool the nuclear fuel during emergency situations if the reactor's cooling water were ever lost.

TVA added a UHI system to the Sequoyah plant in anticipation of an NRC change to the maximum allowable fuel clad temperature of 2,300 degrees during an accident. TVA's decision was based upon an NRC announcement to the nuclear industry in 1972 that the emergency core cooling requirements would be made more stringent after completing an analysis and holding public hearings. In December 1973, NRC issued criteria that included lowering the maximum fuel clad temperature to 2,200 degrees.

NRC is still reviewing UHI, but expects to be finished in June 1975. TVA has no guarantee the UHI will provide the margin of safety needed to operate the plant at full power.

TVA officials estimated the UHI cost at $12.5 million. This cost includes two new buildings required to house UHI equipment.

SECONDARY SIDE WATER CHEMISTRY

The plant's second water cycle, referred to as secondary side water, is designed to change water to steam and turn the turbines that produce electricity (see Figure 1). After the steam turns the turbines it is condensed back to water and repeats the steam generation cycle. Water is added to this system only to compensate for evaporation.

Secondary side water contains impurities which form deposits inside the closed-loop system. These impurities must be removed to maintain efficient operation of the steam turbines.

A plan to remove the impurities by chemical treatment was originally designed for Sequoyah. In October 1972, the system's designer determined that more chemicals than originally planned were necessary to remove the impurities. The plant's capability to treat and remove the impurities also required expansion. A new system referred to as "reverse osmosis" was designed to provide greater water chemistry control. This system cost $1 million.

In August 1974, industry reports showed that certain chemicals cause wear on the system's internal parts. TVA developed a new treatment plan and added another system to keep the water cleaner and thereby reduce maintenance.

This new system referred to as "full flow condensate demineralizer" is estimated to cost $11 million and is not included in the $675 million cost estimate. The demineralizers should not delay the construction project because the plant can operate without it. The demineralizers are planned for completion 1 year after the plant starts commercial operation.

PIPE BREAK

In 1972, NRC recognized that a steamline pipe break could endanger the plant's safety equipment. For example, nuclear plants' main steamlines pass near control rooms, cable spreading areas, electrical equipment, and other engineered safety features. Because of this, NRC published new criteria requiring safety equipment adjacent to steamline pipes to be designed to withstand the sudden release of high pressure steam or any pipe-whipping that could result from a steam pipe break.

The effect of NRC's new criteria required utilities to make extensive design and construction changes to plants under construction. TVA had started installing a few pipe systems at that time, and these systems had to be reanalyzed and redesigned. The redesign required relocating pipes, adding pipe restraints, strengthening structures, and adding walls.

COOLING TOWERS

Two cooling towers 459 feet high and 535 feet in diameter at the base were recently added to the Sequoyah design at a cost of $50 million in order to comply with EPA requirements to lower the temperature of water released by the plant. The towers are linked to the third water cycle (see Figure 1) which passes through a portion of the plant's system before returning to the Chickamauga Lake, or before recirculating if the water cycle is operating in a closed-loop mode. The water temperature in the third cycle increases up to 30 degrees above the inlet water temperature.

Instead of cooling towers, TVA originally planned to use an underwater diffuser pipe system to mix the plant's warm water with the cooler lake water. This design was based on the State of Tennessee's 1968 proposed thermal standards of 93 degrees with no more than a 10 degree rise. The Tennessee Stream Pollution Control Board approved these limits, but EPA and its predecessor on environmental matters, the U.S. Department of Interior, did not approve pending further study.

In 1971, EPA directed Tennessee to hold public hearings on water temperature standards. Tennessee upheld their standards as originally proposed. However, in 1972 EPA directed Tennessee to lower the temperature limits to 86.9 degrees with a maximum rise of 5.4 degrees.

EPA's policy statement on thermal criteria states: "the individual water body must be analyzed to define the individual species or community to be protected." EPA officials did not make a specific study of the Tennessee River but stated that the standards set were based on the River's historical temperature records; the effect of added heat on the total water quality, especially the stream's capacity to absorb organic waste; and protecting the reproduction and growth of two game fish--the Walleye and Sauger. EPA relied heavily on Ohio River studies to set the temperature standards, especially regarding protection of the game fish.

EPA officials stated that the original State thermal standards for the Tennessee River would have been damaging to the river as well as to its aquatic life. However, they did not know the extent of damage the river would sustain or the percentage of fish that would be killed. They stated that under the law, they are obligated to protect the river and its aquatic life from any damage, no matter how little.

TVA officials stated that scientific justification is not available for the EPA thermal standards for the Tennessee River. The Tennessee State Department of Water Quality agrees with TVA's position. These officials believe the EPA thermal standards were established to obtain uniform state codes for the Tennessee River,1/ and claim the cooling tower costs outweight the benefits. An EPA official informed us that cost-benefit factors are not sole criteria for EPA decisions.

Under a cooperative effort with EPA, TVA is building a biothermal research center at its Browns Ferry nuclear plant to study thermal effects on aquatic life. Meanwhile, TVA must comply with existing EPA standards, and to do so it is installing cooling towers at all of its nuclear plants at an estimated cost of $400 million.

Cooling towers use electricity which reduces the electrical output available for commercial use. TVA estimates that if the towers are operated in a partial mode, that is where water passes through the towers and is released into Chickamauga Lake, the total average annual reduction will be about 5,670 kilowatts. If the towers are operated in a closed-loop mode where the water continually circulates 100 percent of the time, a third tower may be needed at a cost of at least $25 million. This would require considerably more electricity with an estimated average annual reduction of about 39,190 kilowatts.

1/ Similar standards had previously been established in the State of Alabama through which the Tennessee River also flows.

ESSENTIAL RAW COOLING WATER PUMPING STATION

The essential raw cooling water pumping station provides cool water to the reactor system during normal operations and serves as a coolant system in the event of a major accident.

The pumping station was originally designed and built along the shore of the intake canal. This canal is the plant's source of cool water. However, the cooling towers are operated under a closed-loop mode as discussed above, the warm cooling tower water will be recycled into the intake canal. This will cause the canal water to become too warm to properly cool the reactor system. A new pumping station must therefore be built at another location where a sufficient supply of cool water is available. This new station and its connections to the powerhouse is estimated to cost $25 million, the full cost of which is not reflected in the current project estimate of $675 million.

## CHAPTER 5

## CONCLUSION AND RECOMMENDATION

Concurrent design and construction of nuclear plants is a normal industry practice according to NRC officials, and plants are often custom-designed making an extensive NRC review necessary to ensure public health and safety. As new technology is applied, NRC reviews become even more important. An extended period of time usually elapses between NRC's two-stage licensing review process--42 months in the case of TVA's Sequoyah plant -- and concurrency, customization, and new technology can increase the likelihood NRC will find problems with a utility's plant design. The result can be modified designs and backfits which translate into added costs and delayed schedules.

NRC officials acknowledged there was infrequent communication with utilities about specific plant designs and related problems during the interval between NRC's two-stage review. They informed us of ways utilities can stay informed of NRC requirements and acceptance criteria.

We believe it may be possible to reduce or avoid some modifications to nuclear plants if NRC maintained surveillance over critical features of a plant's design during the interval between its two regular reviews. Except for safety, the main concern should be to assist the utility in avoiding future increased costs and delayed schedules.

We recommend that NRC re-examine its licencing review procedures and practices with the objective of maintaining surveillance over nuclear plant designs during the interval between its two regular reviews -- particularly designs prepared concurrently with construction -- and of finding ways to provide concurrent assistance to utilities in order to reduce costs and maintain schedules.

Matter For Consideration

Several bills were introduced in the 93rd Congress to help eliminate delays in the nuclear licensing process and to generally improve licensing procedures. Two features dealt with standardized nuclear plant designs and pre-selected nuclear plant sites. The latest bill to incorporate these features and to amend the Atomic Energy Act was H.R. 16700. Hearings were held but not completed.

The Congress may wish to continue reviewing the advantages and disadvantages associated with standardization and pre-selected plant sites, and consider appropriate legislation to help reduce nuclear plant lead time.