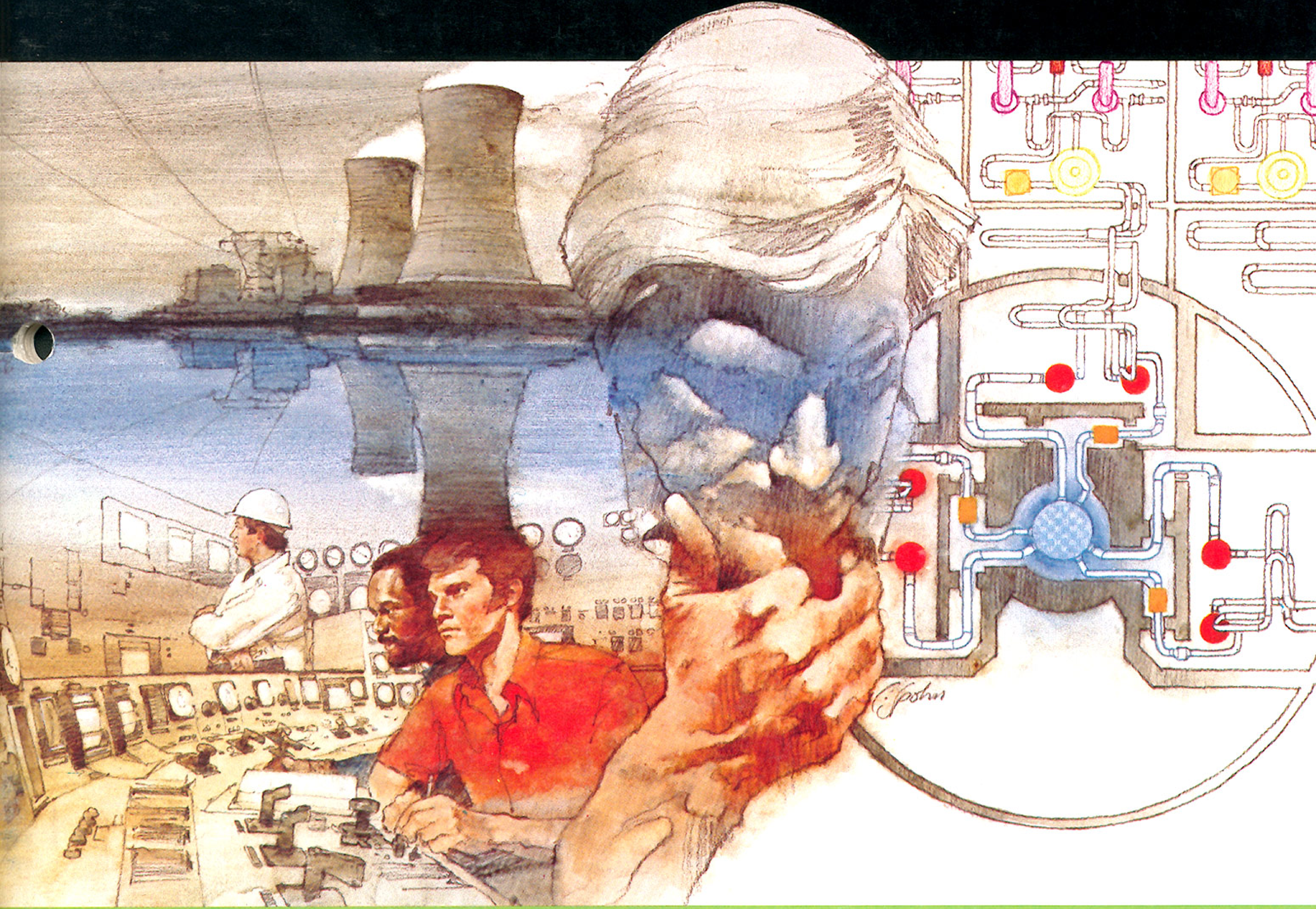
ATARI® 400*/800™

COMPUTER PROGRAM

SCRAM™

(A Nuclear Power Plant Simulation)



ATARI®

A Warner Communications Company

Model CX4123
Use with
ATARI® 400™* or ATARI 800™
PERSONAL COMPUTER SYSTEMS

An 8K ATARI® 400TM Personal Computer System must be upgraded to 16K of RAM at an ATARI Service Center.

SCRAM™
A NUCLEAR POWER PLANT SIMULATION

ATARI®

A Warner Communications Company

PRINTED IN U.S.A

PREFACE

WHAT "SCRAM" MEANS

University of Chicago, December 2, 1942, 3:36 P.M.

Under the stands at Stagg Field, a group of scientists gathers to conduct an epochal experiment. They are going to start up the world's first nuclear reactor. How will it behave? None of them knows for certain. They have two basic problems: how to start the reactor and...perhaps more important...how to stop it once it's started. What forces will they unleash if they fail to stop it promptly?

Three safety systems are prepared: an automatic electrical system, a chemical system manned by three scientists on top of the reactor, and a control rod called "Zip." Zip is lowered into the reactor by heavy weights. To start the reaction they must pull Zip out of the reactor and ti• it in place with ropes. A scientist with an axe hovers over the rope. In case of trouble he will cut the rope, let Zip fall into the reactor, and stop the reaction. He watches group leader Enrico Fermi intently. One word from Fermi and he will chop the rope. That word is **SCRAM**..."Start Cutting Right Away, Man!" But Fermi does not call "SCRAM"; the reactor performs as expected.

Three Mile Island, March 28, 1979, 4:00 A.M.

Deep inside Three Mile Island Nuclear Power Plant Unit 2, a valve in the condensate polishing system fails. Within seconds the main feedwater pumps trip, the turbines trip, and the steam generators are boiling dry. At 4:01 AM a voice calls over the public address system, "We have a turbine trip and a reactor SCRAM." This time things do not happen as expected.

CONTENTS

1

GENERAL INFORMATION ABOUT THE SCRAM™ PROGRAM

AGE RANGE: Age 12 to adult.

PURPOSE

SCRAM™ is more than a game. It is an educational simulation that teaches the principles of nuclear power plant operation in a dramatic and entertaining way. We begin by building a typical nuclear power plant, modeled on Three Mile Island Nuclear Power Plant Unit 2. When the plant is ready, we enroll the user in our training program. This program shows the user how a nuclear power plant transforms nuclear energy into electricity, then trains him to run the plant himself. He even gets a chance to melt the reactor core.

The last phase of the training program is the qualifying exam, which is presented in the form of a game...the SCRAM game. SCRAM tests the user's ability to run the plant under emergency conditions. As earthquakes break one vital component after another, the user tries to keep the plant going. He must generate as much electricity as possible while finding and fixing broken components. It's a race against time. Will he succeed in shutting down the reactor before the core melts down?

For users who need help playing SCRAM, we have a coaching session entitled "How To Succeed at SCRAM" (Section 9). In addition, the Appendix contains some helpful information about the limitations of SCRAM ("Accuracy of the Simulation") and an account of the accident at Three Mile Island. "The Accident at Three Mile Island" is discussed in terms appropriate to the simulation and is especially enlightening after the user has learned to operate the nuclear power plant simulation.

SKILLS

SCRAM develops the abilities to:

- Think logically and objectively
- See patterns in complex systems
- See cause and effect relationships
- Analyze problems and solve them effectively.

CATEGORIES OF USE

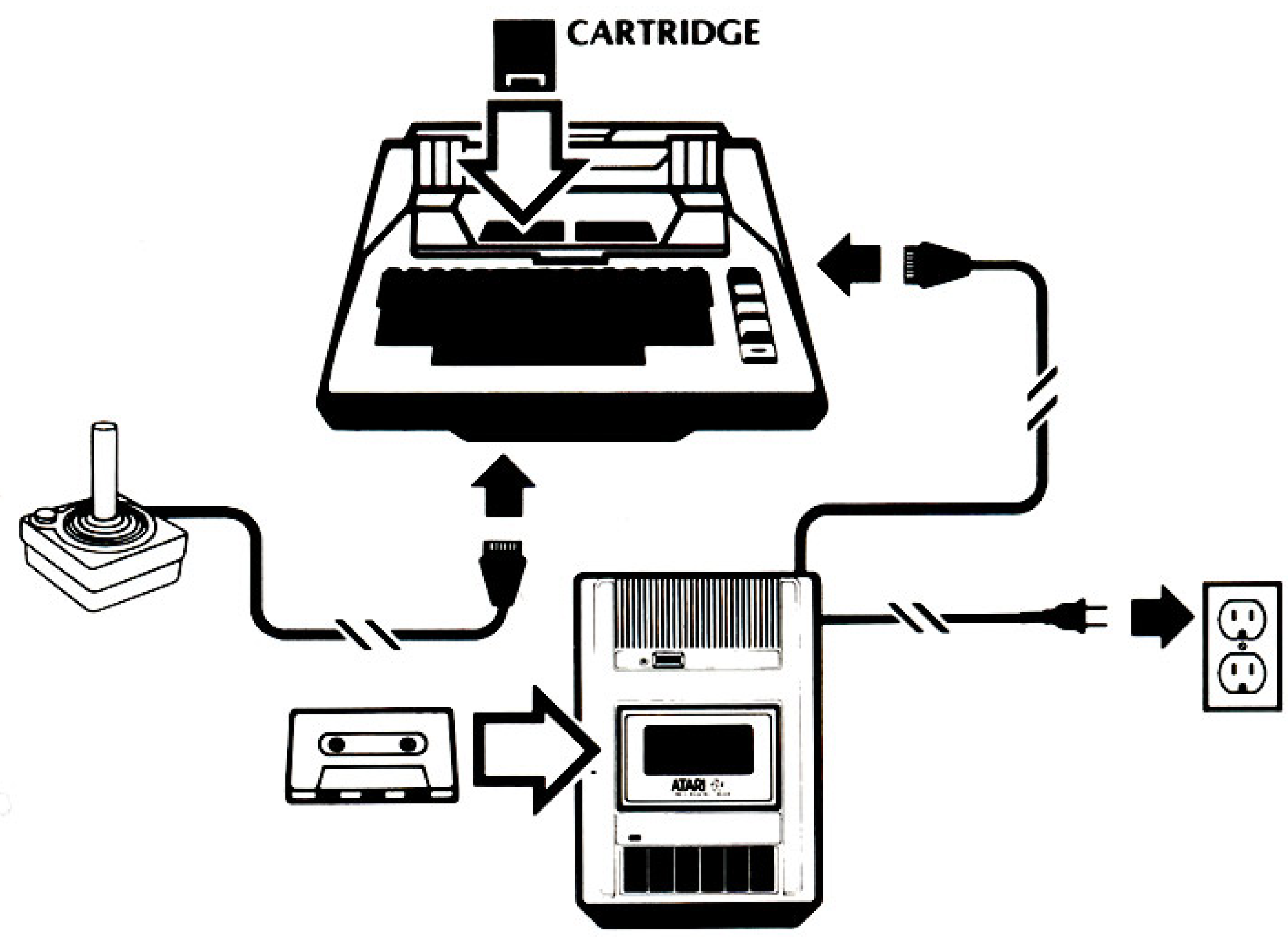
- Education
- Recreation
- Personal Development.

2

SETTING UP

ATARI COMPONENTS REQUIRED

1. ATARI 800™ or upgraded ATARI 400™ Personal Computer System with:
   - Minimum of 16K Random Access Memory (RAM)
   - ATARI BASIC Computing Language Cartridge
   - One Joystick Controller.
2. ATARI 410™ Program Recorder
3. ATARI SCRAM™ Program Cassette



LOADING THE CASSETTE PROGRAM

1. Connect your ATARI 800 or upgraded ATARI 400 Personal Computer System to your television set, as instructed in your Operator's Manual.
2. Connect the data cord attached to your ATARI 410 Program Recorder to the PERIPHERAL connector on the right side of your ATARI Personal Computer System.

   NOTE: If other ATARI units, such as a disk drive or printer, are "daisy-chained" (connected in series) to your computer, connect your 410 Program Recorder to the I/O CONNECTOR of the last unit in the chain.
3. Connect the power cord attached to the ATARI 410 Program Recorder to a wall outlet (110/115 VAC).

4. Load enough RAM into your Personal Computer System to run the SCRAM Program. The Program Cassette contains two versions of the SCRAM Program: 16K and 24K.

   The 16K version was designed especially for the upgraded ATARI 400 Personal Computer System, which cannot accept programs longer than 16K bytes. It will also work with an ATARI 800 Personal Computer System loaded with 16K RAM. This version takes slightly longer to load than the 24K version, but there is no difference in the program content.

   The 24K version can only be used with the ATARI 800 Personal Computer System loaded with a minimum of 24K RAM.

   Besides the 16K or 24K bytes of RAM required for SCRAM, you will need additional RAM if an ATARI Disk Drive system is connected to your Personal Computer System. See NOTE 1 at the end of these loading instuctions for further details.

5. Insert the ATARI BASIC Computing Language cartridge into the cartridge slot of your ATARI Personal Computer System. Use the LEFT CARTRIDGE slot on the ATARI 800 Personal Computer System.

6. Connect the Joystick Controller to CONTROLLER JACK 1 on the front of your ATARI Personal Computer System.

7. Turn on your television set.

8. Turn on your ATARI Personal Computer System. The POWER switch is on the right side of the computer console.

9. If all equipment is properly connected and powered up, your television screen should display the **READY** prompt, with the white cursor just below. (See NOTES at the end of these installation instructions if you have loading problems.)

10. Press **STOP/EJECT** on your ATARI 410 Program Recorder to open the cassette door.

11. Hold the SCRAM Program Cassette so that the tape leader faces you and the correct side faces up. If you are using the upgraded ATARI 400 Personal Computer System or an ATARI 800 Personal Computer System loaded with 16K RAM, the label reading "16K" should face up. The 24K version of SCRAM can only be used with the ATARI 800 Personal Computer System loaded with a minimum of 24K RAM.

12. Slide the cassette into the cassette holder and close the door.

13. If necessary, press **REWIND** to rewind the tape to the beginning of the program. When the tape is rewound, press **STOP/EJECT**.

14. Type **CLOAD** on the computer keyboard and press the RETURN key. The computer will "beep" once to remind you to press **PLAY** on the Program Recorder.

15. Press **PLAY** and RETURN to start the tape. Through the window in the Program Recorder note that the tape is turning.

16. After about 20 seconds you will hear a series of "beeps" from your television set. These sounds mean that preliminary program information is being loaded into computer RAM. Loading of the preliminary program is completed when your television screen displays the **READY** prompt.

17. When **READY** appears, type **RUN** and press RETURN. The ATARI logo and **LOADING SCRAM** will appear on your television screen. Your computer will then "beep" once to signal the start of program loading. Check that the tape is turning. After about 20 seconds, you will again hear a series of "beeps." This time they indicate that the SCRAM program is being loaded into computer RAM.

    The 24K version of SCRAM takes about 5 minutes to load. Loading is completed when **BUILDING NUCLEAR POWER PLANT** appears on your television screen.

    The 16K version of SCRAM takes slightly longer to load and loads in two stages. The first stage of loading is completed when **BUILDING NUCLEAR POWER PLANT** appears on your screen. The tape pauses momentarily at that point. After **WAITING FOR NRC LICENSE** appears, the computer "beeps" once to signal the start of the last stage of loading, and the tape continues turning. The 16K version of SCRAM is completely loaded when the text window appears (see Figure 2) and the nuclear power plant on your screen is operating. Listen for the roar of the turbines. If you don't hear the turbines, turn up the volume on your television set.

18. When the SCRAM program is completely loaded, **REWIND** the tape to the beginning.

    NOTE: Always rewind the tape to protect it from oxidation, which can cause premature tape failure.

NOTES

1. If an ATARI Disk Drive is connected to the computer, the Disk Operating System (DOS) and system software use some of the available RAM, in addition to the RAM required to run the program. The amount of RAM required by DOS depends upon the version of DOS you are using. This overhead should be taken into account when calculating the total amount of RAM required for the program.

2. If you have problems loading SCRAM and you have peripherals in addition to the Program Recorder connected to the computer, try disconnecting the peripherals and connecting the Program Recorder directly to the computer to isolate the problem. If problems persist, consult the ATARI 410 Program Recorder Operator's Manual.

3. If the SCRAM display remains unchanged on the screen for longer than 9 minutes, it will change colors to protect your television screen. There is nothing wrong with your television set or the program. Just press any key on your computer keyboard to return the display to normal.

3

BUILDING SILICON VALLEY NUCLEAR POWER STATION UNIT 2

After you have loaded SCRAM, type **RUN** and press the RETURN key to start building Silicon Valley Nuclear Power Station Unit 2. Building a nuclear power station would normally take about 5 years. We build one while you watch.

Now that our power station is completed, we have to get a license to operate from the Nuclear Regulatory Commission (NRC). The NRC will issue the license after studying and verifying our Environmental Impact Report and Final Safety Analysis Report. Normally we would have to wait another 5 years for our license, but with our connections we can get a license in 5 seconds. When you hear the rumble of the turbines, the Silicon Valley station is operating.

4

HOW TO USE THE SIMULATION

The nuclear power station you see on your television screen, Silicon Valley Nuclear Power Station Unit 2, is a simulation or simplified working model of a real nuclear power plant. It is similar to Three Mile Island Nuclear Power Plant Unit 2. Like the Three Mile Island plant, the Silicon Valley plant generates electricity by transferring energy in the form of heat from the nuclear reactor to the turbines that drive the electricity generators.

In the next section, Section 5, you will learn how to run the Silicon Valley station. We have prepared a special training program to qualify you as an operator. We start with a tour of the station. You see how the plant is designed to transfer heat from the reactor to the electricity generators, and you learn what the principal components do. Next you perform some controlled experiments and note what happens to the system. You lower the control rods into the reactor core, open and close valves, and turn pumps on and off. You even get a chance to melt the reactor core...a unique feature of our training program.

In Section 6 you learn how heat flow is affected by changes in temperature and pressure. This course is called Thermodynamics 1A. It prepares you to read the station indicators. The indicators, discussed in Section 7, keep you informed of the temperature, pressure, and power output. If you can read the indicators fast, you will be well prepared for your qualifying exam, the SCRAM game.

The SCRAM game tests your ability to generate electricity under emergency conditions without melting the reactor core. If you pass the exam with a high score, you will qualify as a REACTOR OPERATOR. If you pass with honors, you become a SENIOR REACTOR OPERATOR. In Section 8 we will tell you how to play SCRAM. But first you must complete the training program to understand how the nuclear power plant works.

5

OPERATOR TRAINING PROGRAM

TOURING THE NUCLEAR POWER STATION

Our Silicon Valley station houses a pressurized-water reactor (PWR) system. Its three water loops transfer heat from the reactor to the turbines and from there to the cooling tower. The cooling tower gives up heat to the air and returns the water to the third water loop.

First we'll take a quick tour of the station to see how the heat transfer system works. Then we'll repeat the tour and take a closer look at the principal components.

OVERALL VIEW

Heat used by the system to generate electricity is produced by nuclear fission chain reactions in the core of the reactor. Fission simply means splitting. Nuclear fission is the process of splitting the nuclei of atoms of fissionable material such as uranium-235. The nuclei are split by bombarding them with subatomic particles called neutrons. When the nuclei split, they release more neutrons, some of which strike and split other nuclei. Thus, a fission chain reaction is initiated. A fission reaction releases energy stored in the nuclei and generates great quantities of heat.

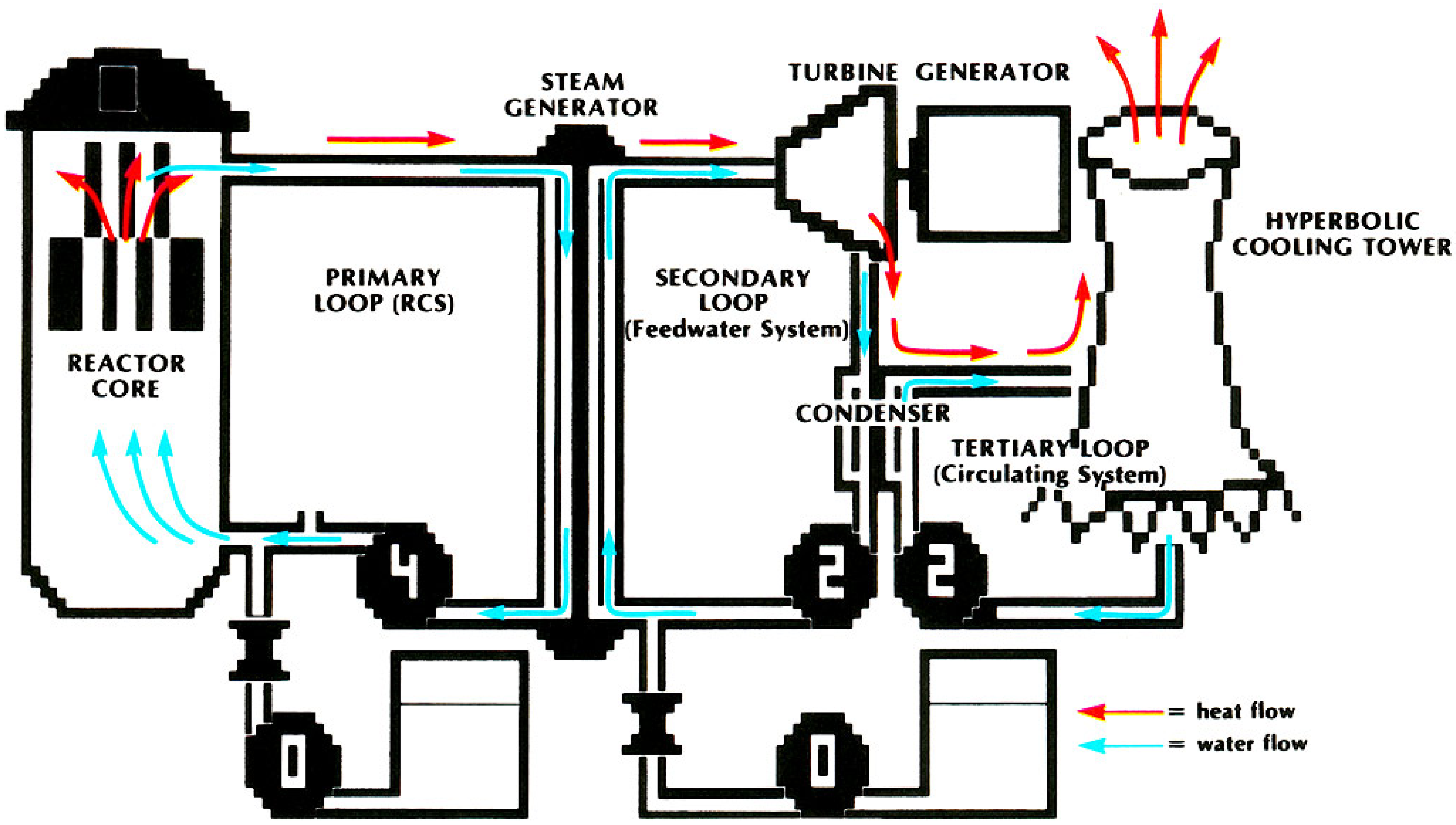


Figure 1. Heat Transfer in the PWR System

Look at Figure 1. The heat generated by nuclear fission flows from the reactor core into the cooling water of the reactor vessel and is carried by water circulating in the Primary Loop to the steam generator. The steam generator is a heat exchanger. It passes heat from the Primary Loop into the water of the Secondary Loop and boils the water into steam. The steam flows to the turbines, which drive the electricity generators. A turbine and generator unit is called a turbogenerator.

The spent steam from the turbogenerators flows to the condenser, which is also a heat exchanger. The condenser removes heat from the steam and transfers it to water in the third or Tertiary Loop. This loop carries the heat to the cooling tower, which transfers it to the air.

Now we'll return to the starting point of our tour and look at the system in a little more detail. Refer to Figures 1 and 2.

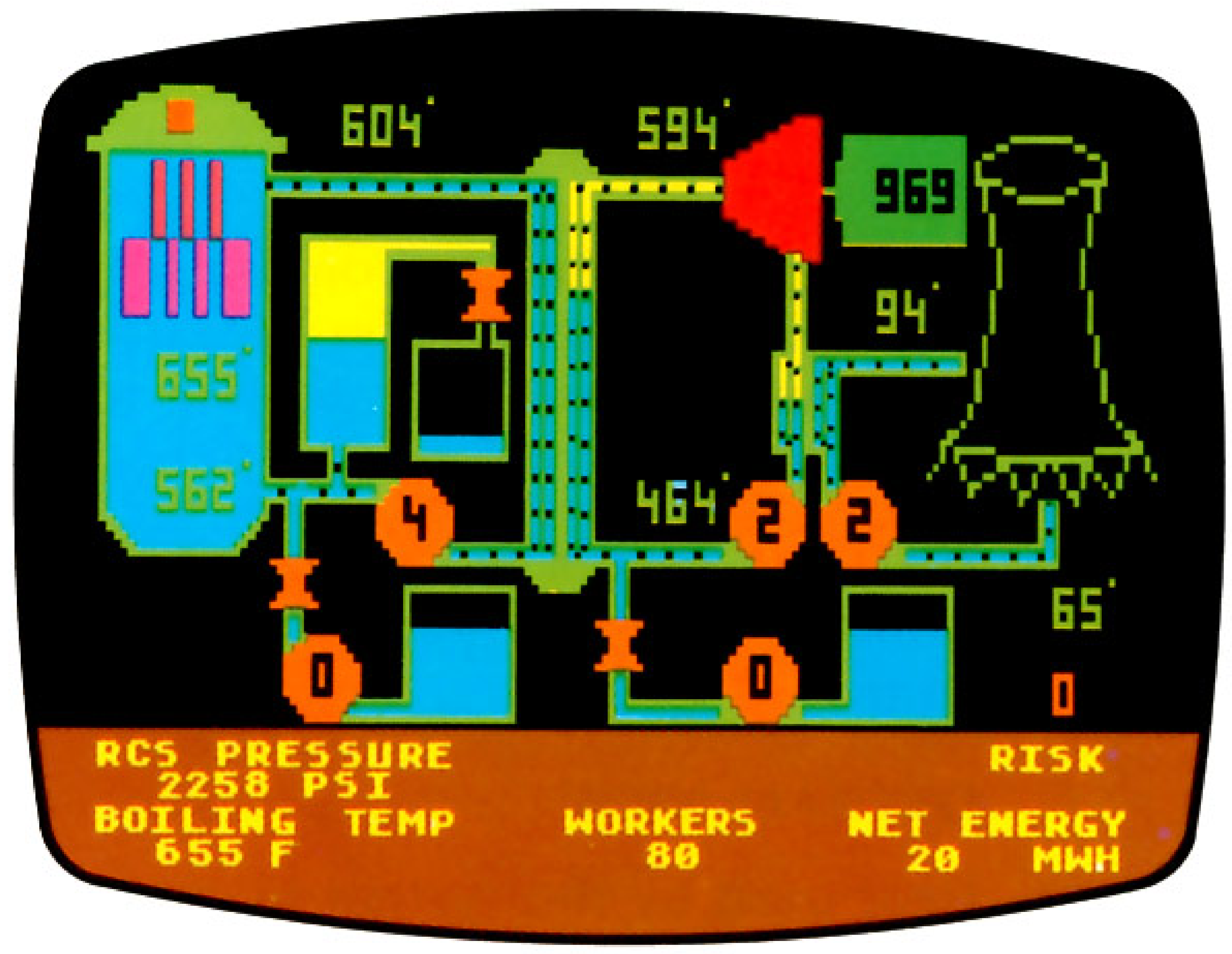


Figure 2. Silicon Valley Nuclear Power Station Unit 2

PRIMARY LOOP (Reactor Coolant System)

The Primary Loop is known as the Reactor Coolant System (RCS). The loop or system begins at the four RCS pumps (represented by the orange octagon with the number 4), which pump cooling water into the reactor vessel. The water cools the reactor by absorbing heat and carrying it out of the vessel. The heat is carried to the steam generator, which transfers it to the water in the Secondary Loop. Cooled water is then pumped back to the RCS pumps. Let's look at the principal components in this loop.

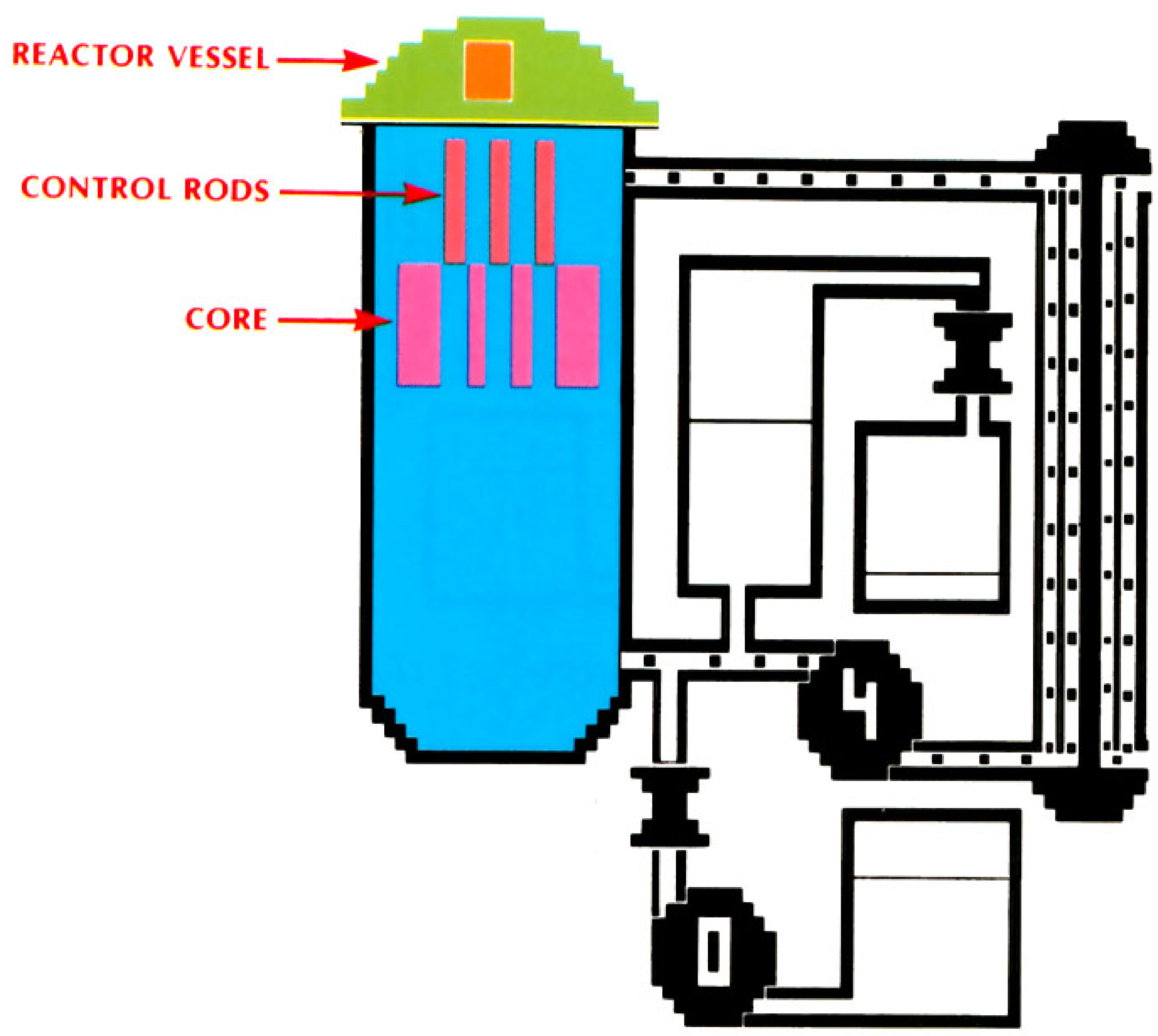


Figure 3. The Reactor

Reactor. The reactor (Figure 3) consists of the core, control rods, and reactor vessel. The **core** is a bundle of fuel rods stuffed with pellets of uranium fuel. Between the rods are spaces for circulation of cooling water and insertion of the control rods. A staggering amount of power can be generated by the core. A typical output is some 3 billion watts, which is equivalent to about 4 million horsepower. Even more astonishing is the concentration of power. All this power is concentrated in a reactor core that is not much bigger than a microbus. The core can keep triggering nuclear reactions and generating power for a year without additional fueling.

The **control rods** are made of material which absorbs neutrons that trigger chain reactions. When we lower the control rods all the way into the reactor, all neutrons are absorbed, all chain reactions stop, and the core cannot generate power. We say the reactor is "scrammed."

If we lower the control rods only partway into the core, some neutrons remain to trigger chain reactions, and the core generates some power. The reactor is not "scrammed" in this case because some reactions continue. To scram the reactor we must lower the rods all the way into the reactor and stop all reactions.

If we raise the control rods completely out of the reactor core, neutrons fly freely through the core triggering chain reactions and the core generates maximum power.

The **reactor vessel** (Figure 4) is a heavy steel container filled with water. Water enters through a pipe at the bottom of the vessel, absorbs heat from the core, and exits through a pipe at the top. As shown in Figure 4, the temperature of the water is 562 degrees Fahrenheit at the inlet to the reactor vessel, 655 degrees Fahrenheit at the "skin" or surface of the core, and 604 degrees at the outlet from the vessel. The temperature of the water at the "skin" of the core is the same as the temperature of the core.

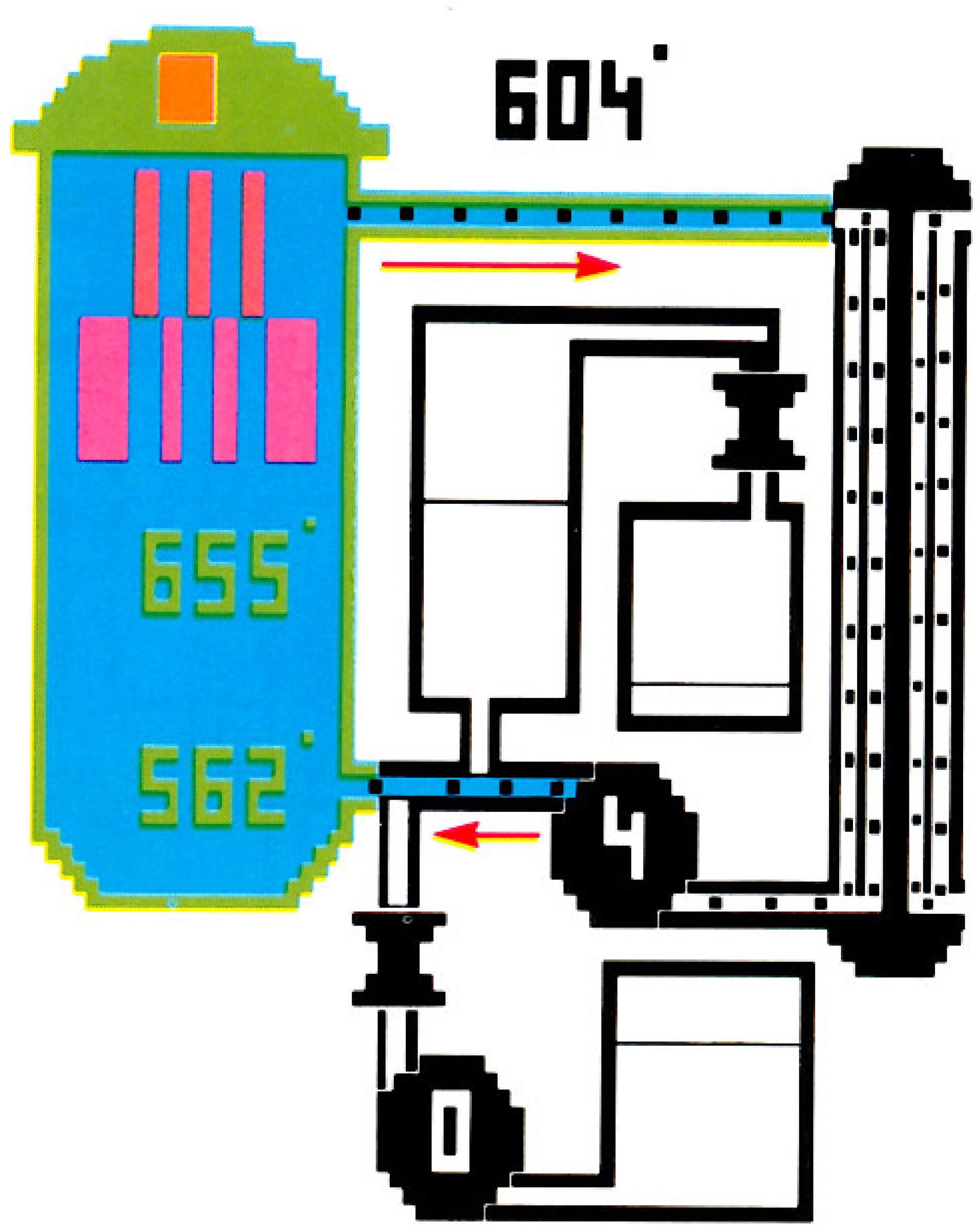


Figure 4. The Reactor Vessel

Pressurizer. The pressurizer (Figure 5) regulates the RCS pressure by dampening pressure transients (sudden increases in pressure) and keeping the pressure within normal limits (2200 to 2300 psi). When pressure is normal, the pressurizer contains half water and half steam bubble. The steam bubble acts like a "cushion" against pressure transients. In the simulation, the color yellow represents steam. You will learn more about the pressurizer when you study Thermodynamics 1A in Section 6.

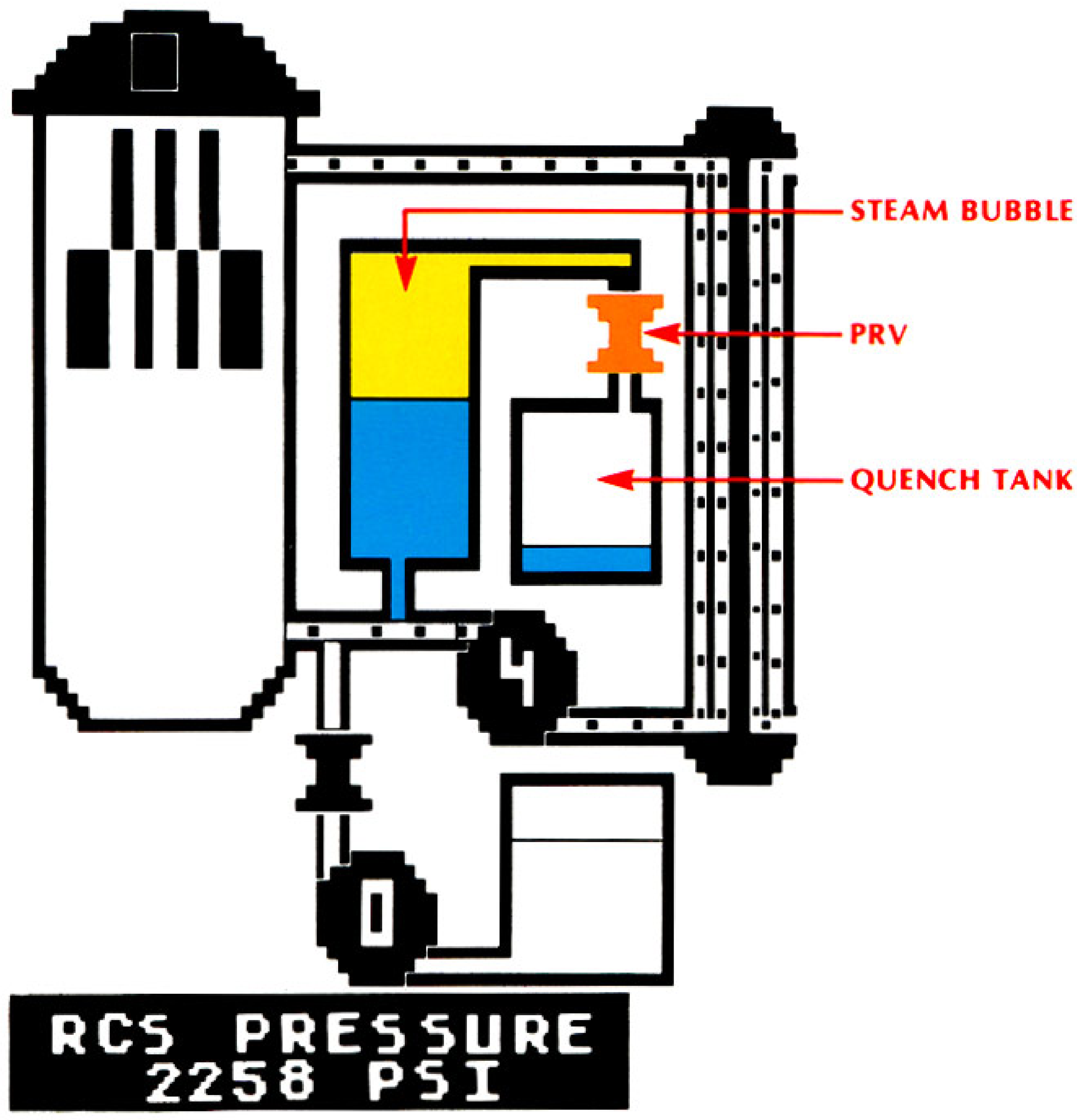


Figure 5. The Pressurizer

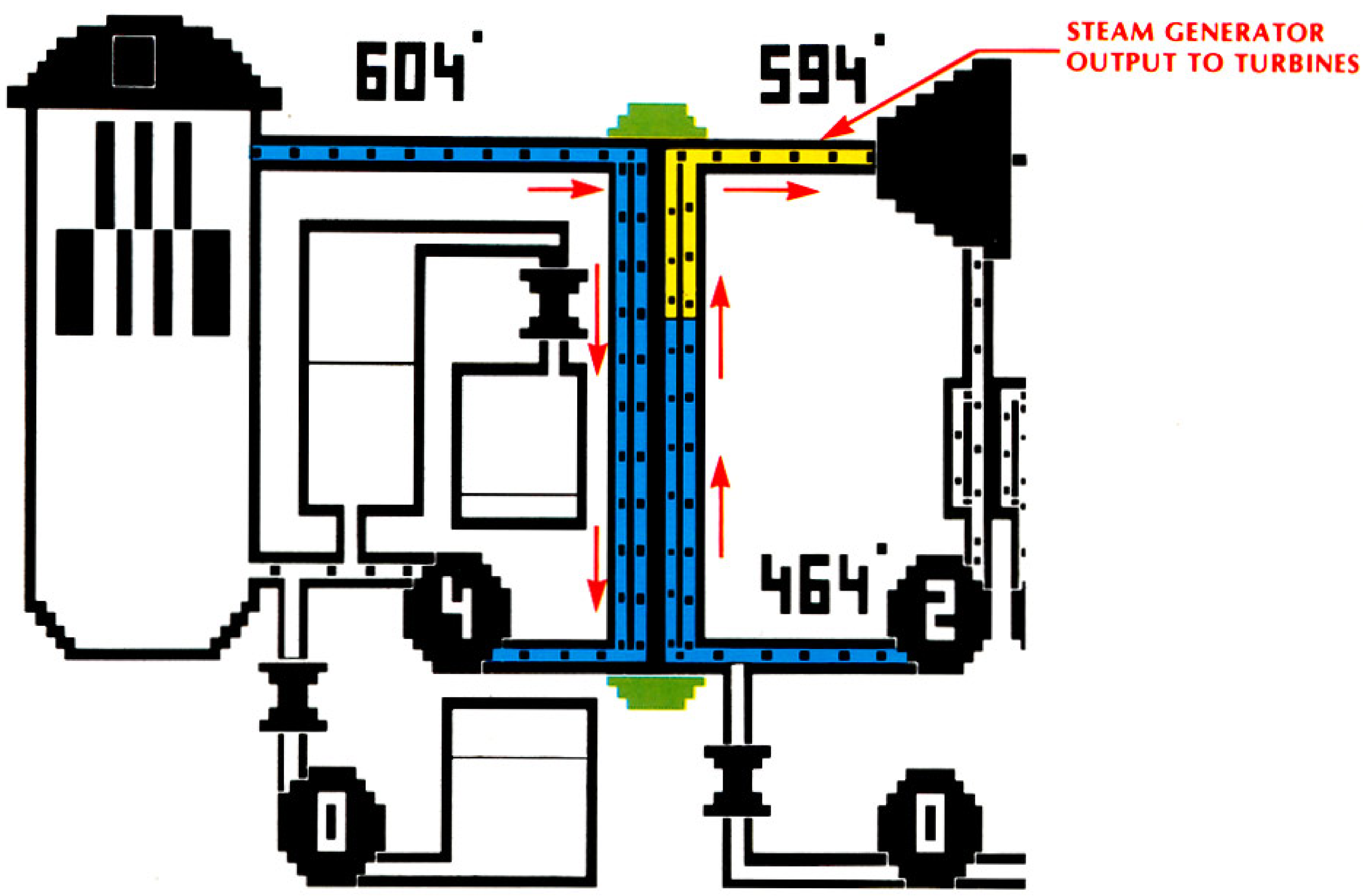


Figure 6. Steam Generator

Steam Generator. Heat from the reactor vessel is carried by the RCS water to the steam generator (Figure 6). This is a very simple piece of equipment. It consists of many small pipes inside a big pipe. Hot water from the Primary Loop or RCS travels downward in the small pipes; cooler water from the Secondary Loop travels upward in the large pipe. The two systems are completely isolated; water from one system never mixes with water from the other. But the heat passes through the thin walls of the small pipes, enters the cooler water in the large pipe, and boils the water into steam.

SECONDARY LOOP (Main Feedwater System)

The Secondary Loop is also called the Main Feedwater System. It starts with the two main feedwater pumps (represented by an orange octagon with the number 2) which pump water into the steam generator. At the inlet to the steam generator the temperature of the water is 464 degrees Fahrenheit.

Hot steam from the generator flows to the turbines, which drive the electricity generators. In the simulation the moving yellow line represents the flow of steam. The temperature of the steam is 594 degrees Fahrenheit.

Spent steam from the turbines is piped to the condenser and condensed into water. The cooled water is piped back to the main feedwater pumps. Now let's look at the turbine, the electricity generator, and the condenser.

Turbine and Generator. A turbine is a giant multilayered fan. If you can visualize a bottle brush spinning inside a bottle, you have a good mental picture of a turbine. The turbine is driven by a combination of "push" from steam entering the turbine and "pull" from steam being drawn into the condenser. The turbine drives the electricity generator, represented by the green rectangle (Figure 7). The rectangle displays the instantaneous power output of the generator, measured in megawatts (MW).

Net energy output, or the total amount of energy generated since you started up the power plant, is shown in the lower right corner of the text window, below the simulation. Net energy is measured in megawatt hours (MWH).

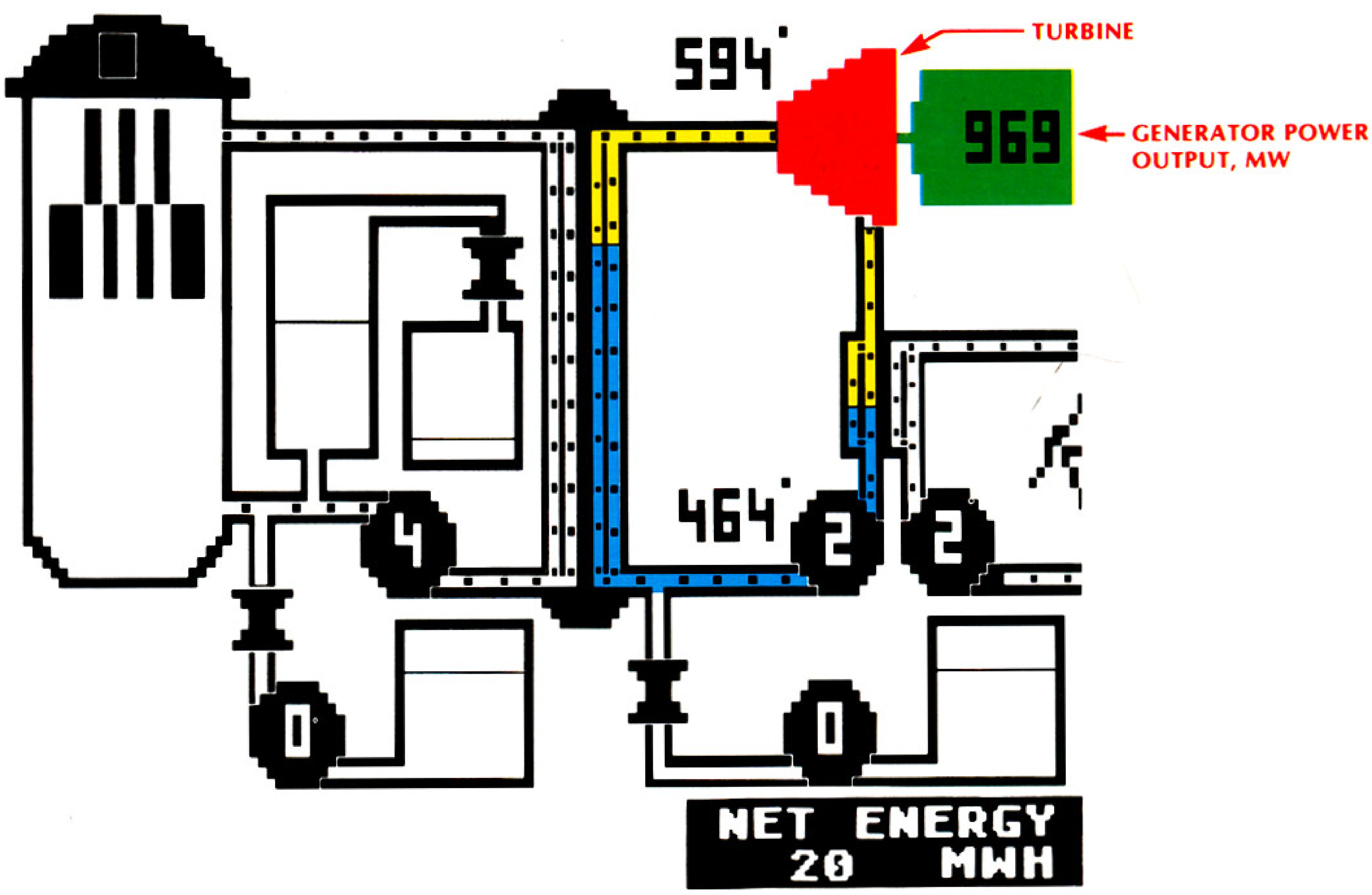


Figure 7. Turbine and Generator

Condenser. The condenser (Figure 8) is a heat exchanger, like the steam generator. It consists of a number of small pipes inside a large pipe. Hot steam from the turbine flows downward in the small pipes and passes heat to cooler water, in the Tertiary Loop, which is circulating upward through the large pipe. After giving up heat, the steam condenses into water and is piped to the main feedwater pumps.

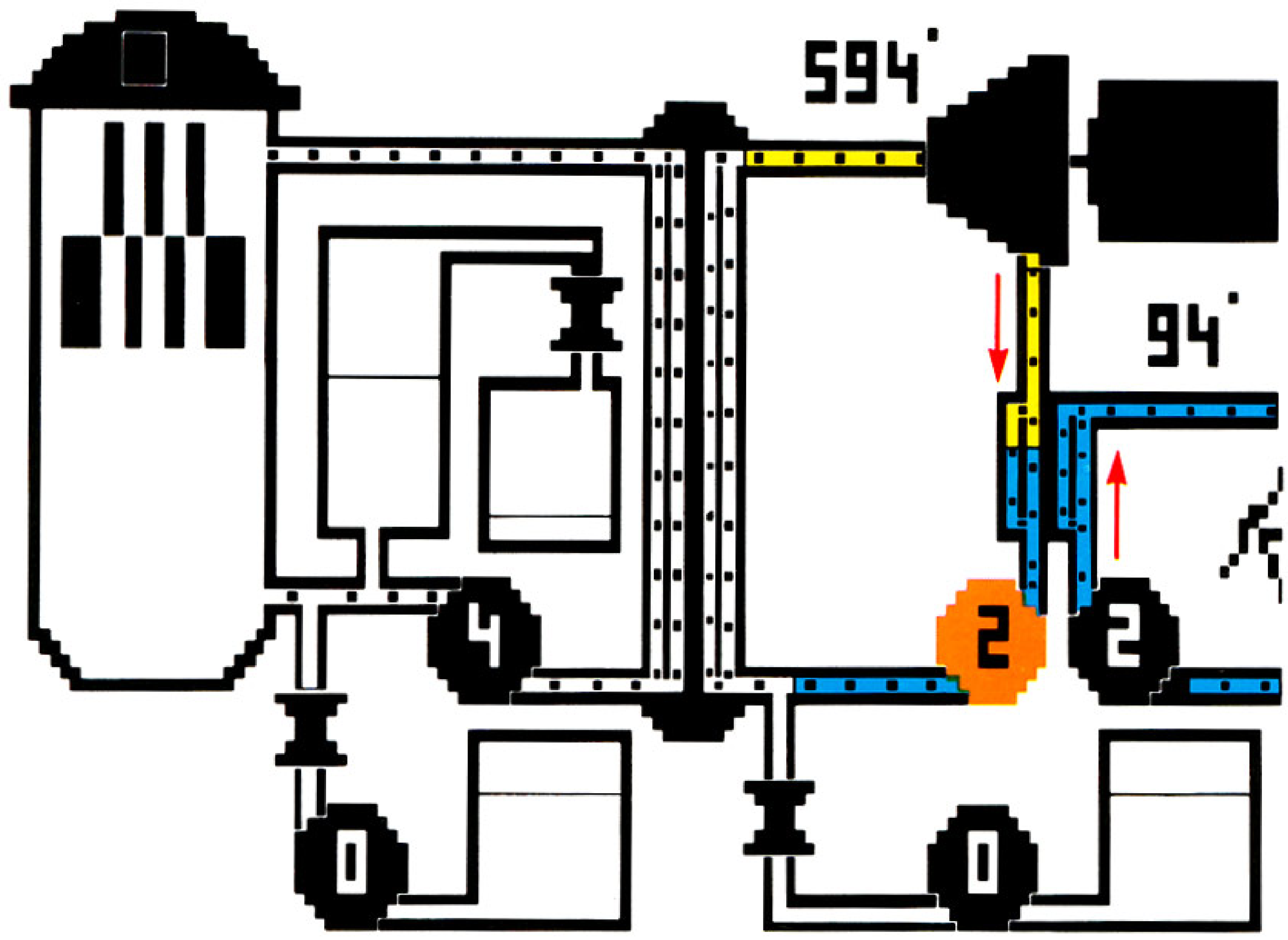


Figure 8. The Condenser

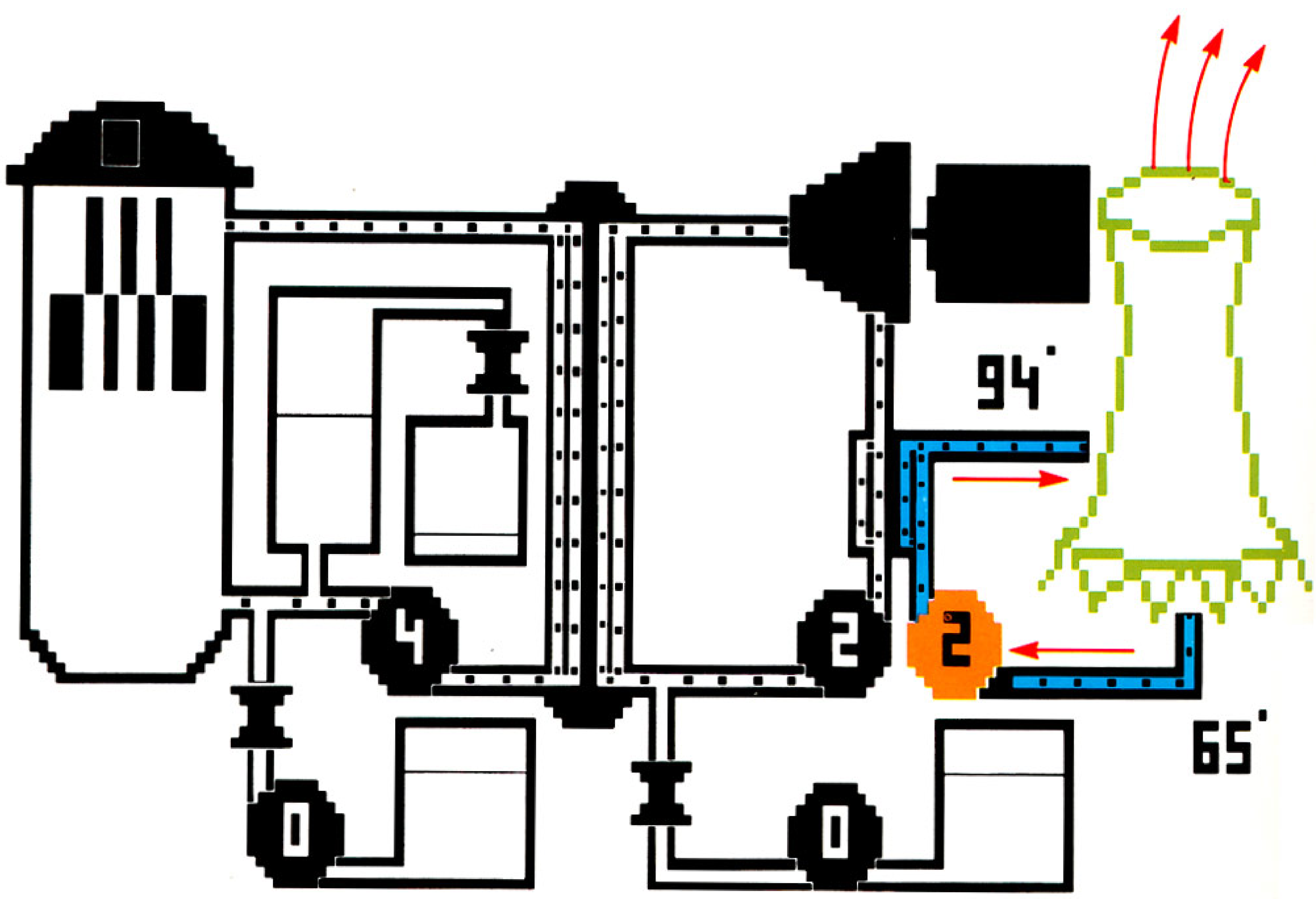


Figure 9. Cooling Tower

TERTIARY LOOP (Circulating Water System)

The third loop starts at the two circulating water pumps, represented by the orange octagon with the number 2. Water pumped into the condenser absorbs heat from the steam and carries it to the cooling tower, which transfers it to the air. Cooled water is then piped back to the circulating water pumps.

Hyperbolic Cooling Tower. In the cooling tower (Figure 9) warm water from the condenser falls from a height of about 20 feet. Some of it evaporates as it falls, transferring heat to the air. The heated air rises to the top of the tower, causing more air to be drawn in at the bottom. Cool water that reaches the bottom of the tower is piped back to the circulating water pumps. Water from the condenser enters the cooling tower at 94 degrees Fahrenheit and exits at 65 degrees Fahrenheit.

HIGH PRESSURE INJECTION (HPI) SYSTEM

The HPI (Figure 10) is also known as the Makeup Water System because it provides water to make up any water deficiency in the RCS. The system consists of a borated water storage tank, four pumps, and a valve. Usually the pumps are turned off, since this system is not needed when the RCS functions normally. When one or more pumps are turned on and the valve is opened, water flows from the tank into the RCS.

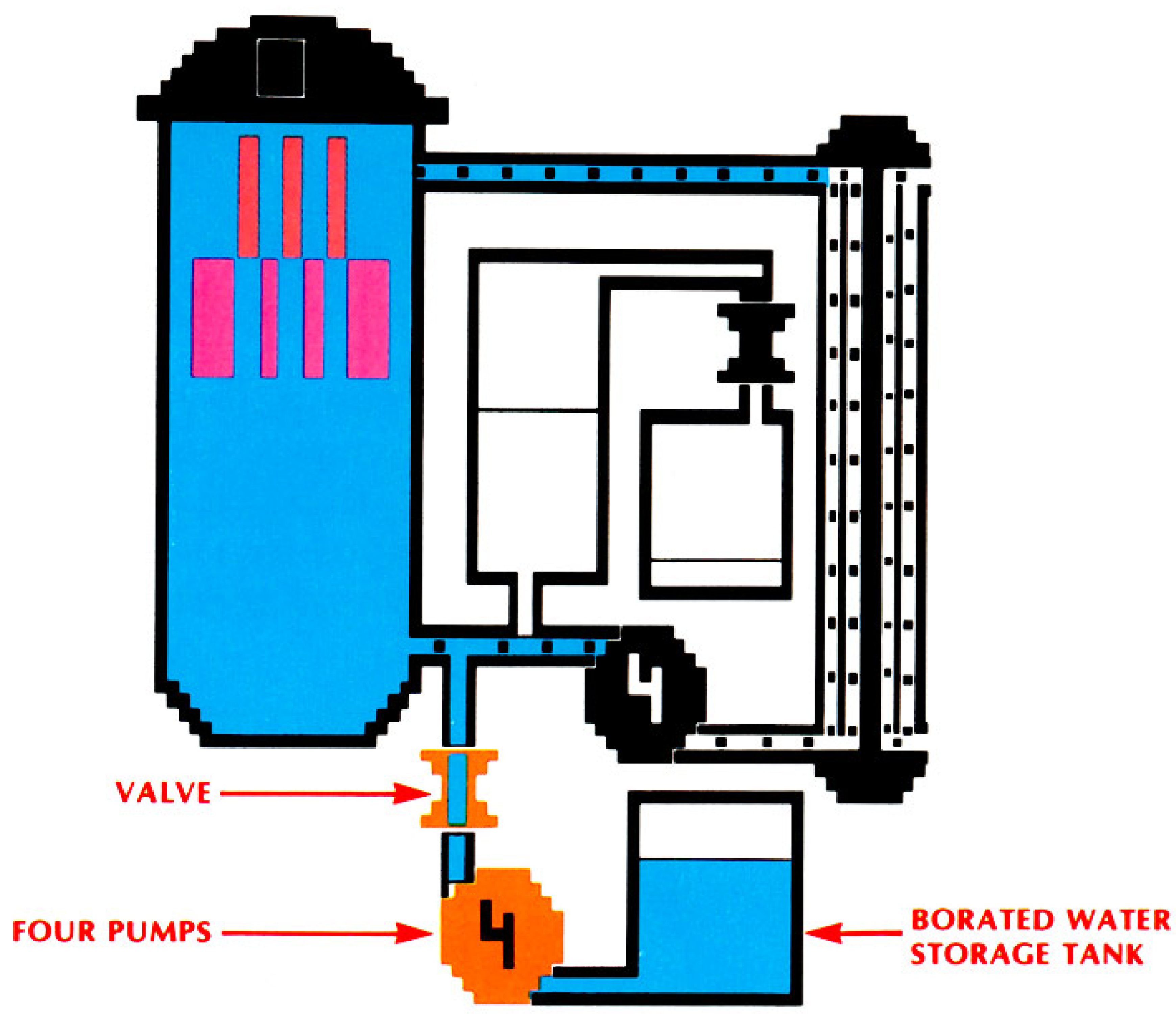


Figure 10. High Pressure Injection System (HPI)

AUXILIARY FEEDWATER SYSTEM

The Auxiliary Feedwater System (Figure 11) backs up the Main Feedwater System in much the same way the HPI backs up the RCS. The Auxiliary System consists of a tank, three pumps, and a valve. Normally the pumps are turned off. When the valve is opened and one or more pumps are turned on, water flows from the tank into the steam generator.

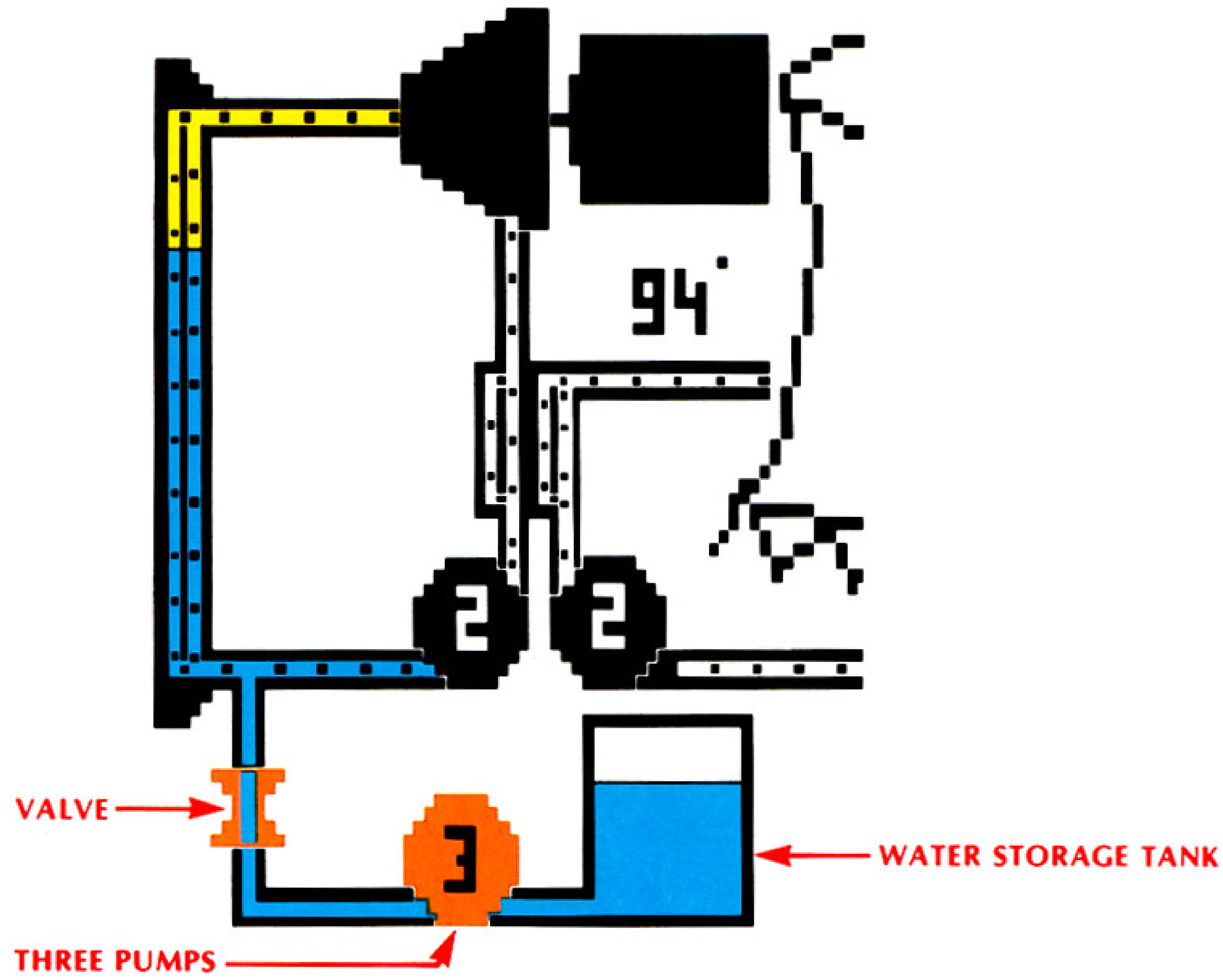


Figure 11. Auxiliary Feedwater System

END OF THE TOUR

Our tour of the Silicon Valley Nuclear Power Station ends here. You can start operating the plant yourself now. If you haven't already done so, plug a Joystick Controller into CONTROLLER JACK 1 (far left jack) on your ATARI Personal Computer System. Orient the Joystick so that the red button is at the top and points to the left of your television screen. Figure 12 shows you how to move the Joystick.

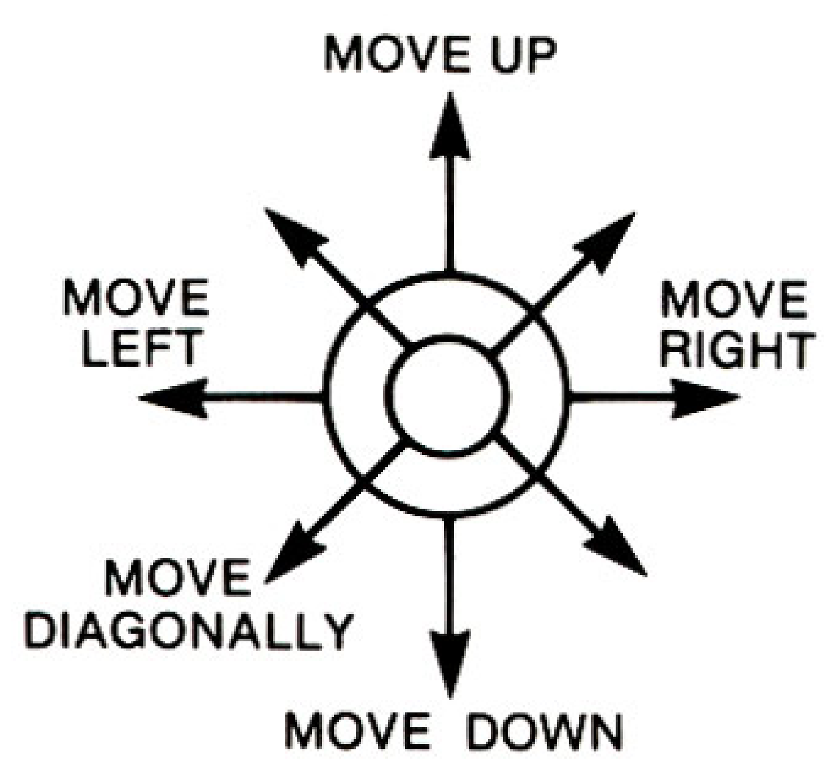


Figure 12. Joystick Moves

RUNNING THE PLANT

After you have attached the Joystick to your computer console, find the cursor in the simulation. It's a flashing colored square in the dome of the reactor vessel. With the Joystick you can move the cursor around the plant to the control rods, the pumps, and the valves. These are the only components you can control with the Joystick.

LOWERING THE CONTROL RODS

The cursor should already be in position in the dome of the reactor vessel, above the control rods. To lower the rods, press and hold in the red button on your Joystick and pull the Joystick straight back toward you. As long as you hold the Joystick in this position, the rods will move down into the core until they cannot go any further.

The more you lower the control rods into the reactor core, the less the core glows. This indicates that the control rods are absorbing neutrons and reducing nuclear power output. When the output decreases, the core releases less heat into the RCS water and temperatures start to drop throughout the plant. The turbines turn slower (you can hear them slow down), and the generators produce less electricity. To help you see the decrease in energy levels throughout the plant, all falling values are underlined. Once the energy output stabilizes at lower values, the underlines disappear.

Now, with your finger on the button, push the Joystick straight up, toward the television screen, and raise the control rods all the way out of the core. Temperatures will start rising throughout the plant, the turbines will turn faster, and electricity output will increase. Values will be overlined until energy output stabilizes at higher levels.

OPENING VALVES AND TURNING ON PUMPS

All the pumps and valves are colored orange and are easy to locate in the simulation. Use the Joystick only, no button, to move the cursor to pumps and valves around the station. To open valves and turn on pumps, press and hold in the red button and push the Joystick straight up. To close valves and turn off pumps, hold in the button and pull the Joystick toward you.

MELTING THE REACTOR CORE

You might as well take this opportunity to melt the reactor core. It's easy enough. All you have to do is move the cursor to the RCS pumps and turn off all four pumps. Make sure that the control rods are all the way out of the core.

With all the RCS pumps shut down, no cooling water circulates through the reactor vessel and the temperature of the core rises rapidly. The water at the skin or surface of the core gets so hot it boils into steam, which insulates the core and makes it even hotter. You will know when this happens because the **STEAM VOIDING!** warning will flash and the station alarm will sound.

When the temperature of the core exceeds 5000 degrees Fahrenheit, the core begins to melt. As 130 tons of intensely radioactive fuel liquefy at the bottom of the reactor vessel, you get a colorful display!

YOUR NEW NUCLEAR POWER STATION

Now that you've gotten that out of your system, start cleaning up the mess you've made. Press START on your ATARI Personal Computer System to rebuild the station. When you hear the roar of the turbines, you're back in business.

Play with your new station to become familiar with it. Move the cursor around the simulation. Open and close valves, turn pumps on and off, and note what happens. But this time be more careful about leaving pumps off too long! If the RCS temperatures rise too high, lower the control rods partway into the reactor core.

The only thing you should not touch for now is the digit over **RISK**. This is part of the SCRAM game and will be explained in Section 8.

6

THERMODYNAMICS 1A

In this course you will learn:

- Basic principles of heat transfer in the nuclear power station
- What happens when temperatures become unbalanced
- Some basic principles of pressure in the nuclear power plant
- What happens when pressures are too high or too low
- How the pressurizer maintains the pressure balance.

When you are finished with Thermodynamics 1A, go on to Section 7 and take the course on Power Station Indicators. These two courses prepare you for your qualifying examination, the SCRAM game.

BASIC PRINCIPLES OF HEAT TRANSFER

To understand how a nuclear power plant operates, you should have a few principles of heat firmly in mind:

- Heat is energy.
- Heat flows through matter.
- Heat flows from hot places to cool places.

In a pressurized-water reactor system, or PWR, heat flows through water from the hottest place in the plant, the reactor, to the coolest place, the air inside the cooling tower. The amount of heat flow depends upon:

- The amount of heat
- The temperature gradient, or the difference in temperature between the hot place and the cool place
- Thermal conductivity, or how easily the heat can flow.

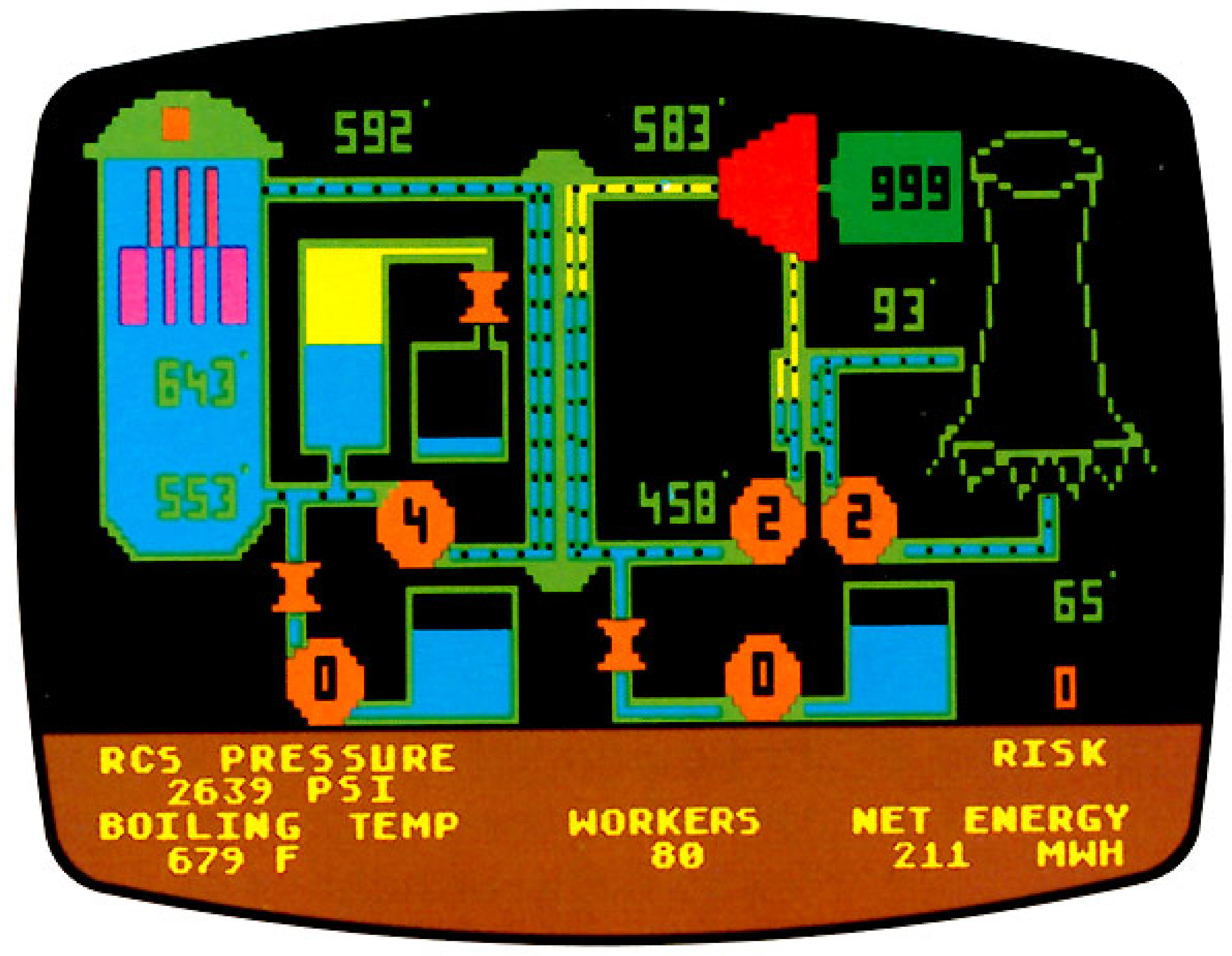
TEMPERATURE GRADIENT

A temperaure gradient exists between two points that are at different temperatures. If the temperatures are not very different, the temperature gradient is small. If the temperatures are quite different, the gradient is large.

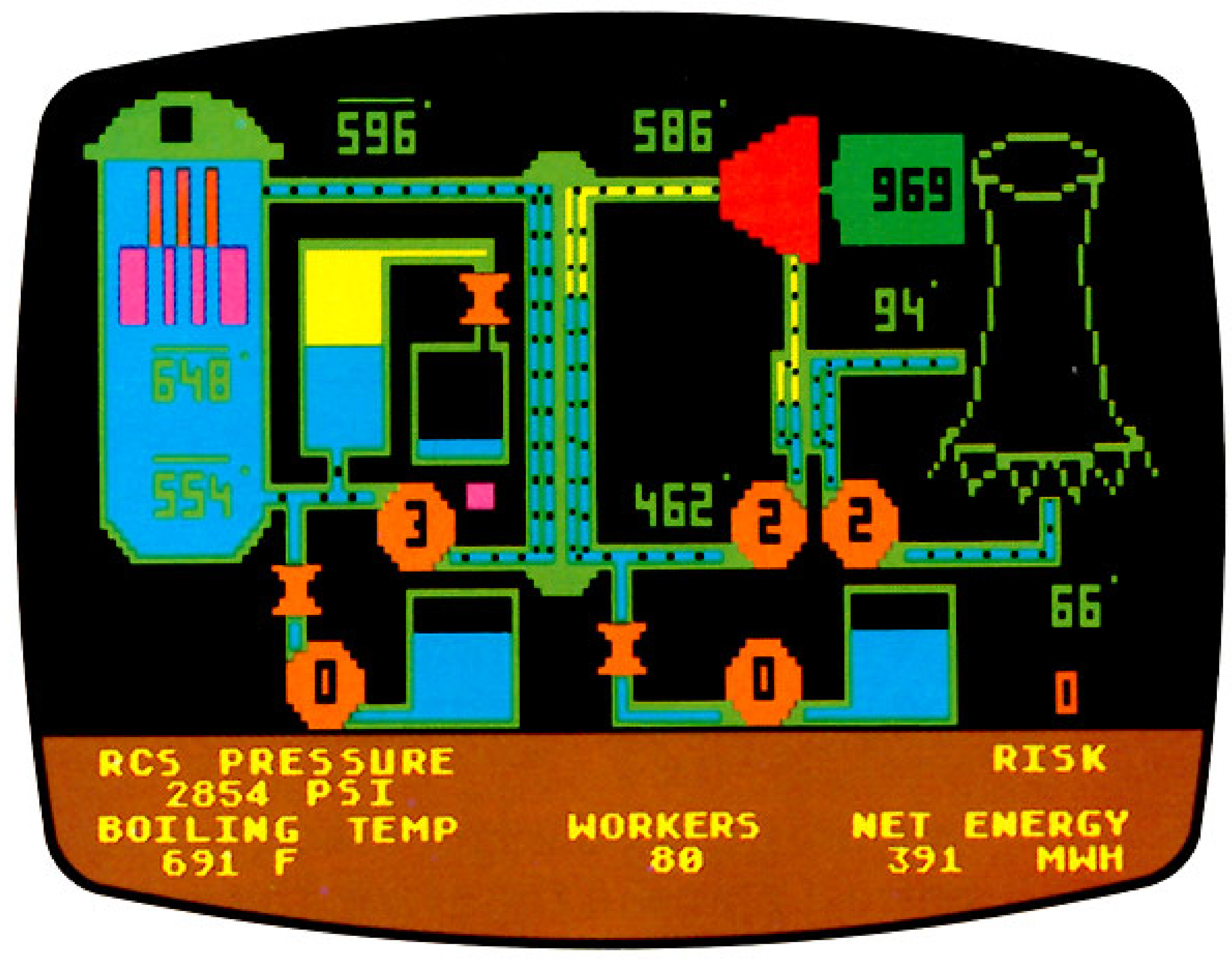
If we want heat to flow from Point A to Point B, Point A must be hotter than Point B. The hotter A is in relation to B...in other words, the larger the temperature gradient between A and B....the more heat will flow.

THERMAL CONDUCTIVITY

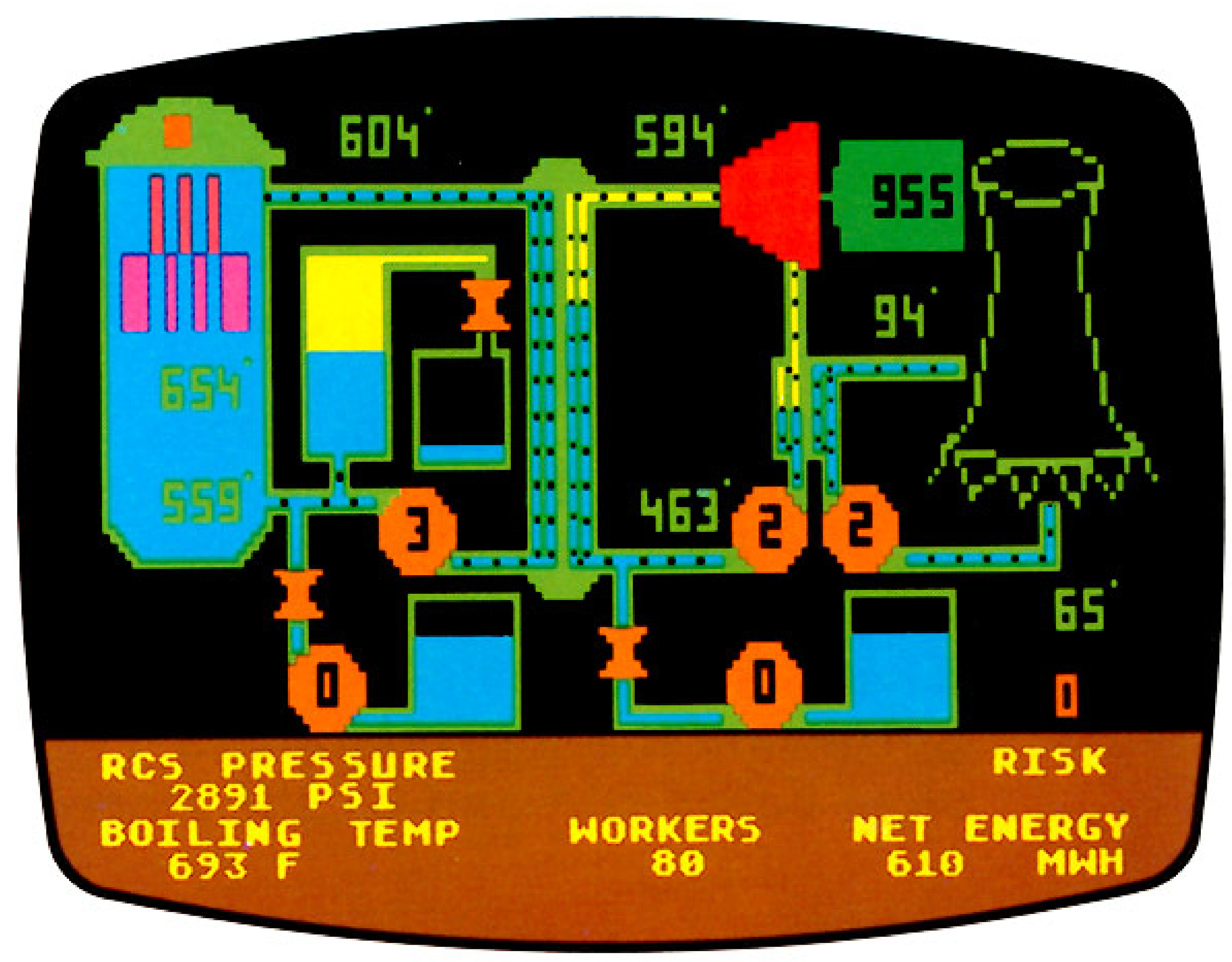
Thermal conductivity is a measure of how easily heat can flow between points. If heat flows easily, thermal conductivity is high. If it cannot flow easily, thermal conductivity is low.



(a) High Thermal Conductivity in RCS



(b) Lower Thermal Conductivity in RCS, Temperatures Rise



(c) Higher Temperature Gradient Core/RCS, Temperatures Stabilize

Figure 13. Thermal Conductivity Vs. Temperature Gradient

In the nuclear power plant, thermal conductivity is high when lots of water is circulating around the source of heat. The idea is simple:

The more water in direct contact with the heat, the more heat you can collect in the water.

For example, thermal conductivity is maximum when all four RCS pumps are operating and water flow around the reactor core is maximum.

THERMAL CONDUCTIVITY VS. TEMPERATURE GRADIENT

There is a trade-off between thermal conductivity and temperature gradient. If the thermal conductivity between Points A and B is high...that is, if heat will flow easily from A to B....then you do not need a large temperature gradient between A and B to maintain good heat flow. However, if you decrease the thermal conductivity, you will have to increase the temperature gradient to maintain good heat flow. Let's see how the trade-off works in the nuclear power plant. Look at Figure 13.

Reactor/RCS. With all four RCS pumps operating, thermal conductivity in the RCS is high (Figure 13a), so a large temperature gradient is not required to make heat from the core flow into the water. However, if you turn off one of the RCS pumps, the thermal conductivity of the Primary Loop will decrease and less heat will flow into the RCS water. The core will retain heat and grow hotter (Figure 13b). When the core is hot enough to create a larger temperature gradient with the RCS, it will release more heat into the water, and the RCS temperature will then stabilize at a new and higher level (Figure 13c).

RCS/Main Feedwater System. Now suppose you turn off a main feedwater pump and cut down on the amount of feedwater flowing through the steam generator. The thermal conductivity of the Secondary Loop will decrease, and less heat will pass from the RCS water into the feedwater. The RCS will heat up until the temperature gradient between the RCS and the Main Feedwater System is large enough to force more heat into the feedwater.

Main FeedWater System/Circulating Water System. Shutting off a circulating water pump will decrease the amount of water flowing through the condenser and decrease the thermal conductivity of the Tertiary Loop. Steam flowing into the condenser will pass less heat into the circulating water. Temperatures in the Main Feedwater System will rise until the temperature gradient between the Main Feedwater System and the Circulating Water System is large enough to force more heat into the circulating water.

HEAT BACKUP

Whatever happens to the temperature gradient at one point in the heat transfer system affects heat transfer all the way back to the reactor. You could think of the heat transfer system as a bucket brigade for heat. If one member of the brigade slows down, the buckets back up and the whole brigade slows down. Figure 14 is an example of heat backup in our nuclear power station.

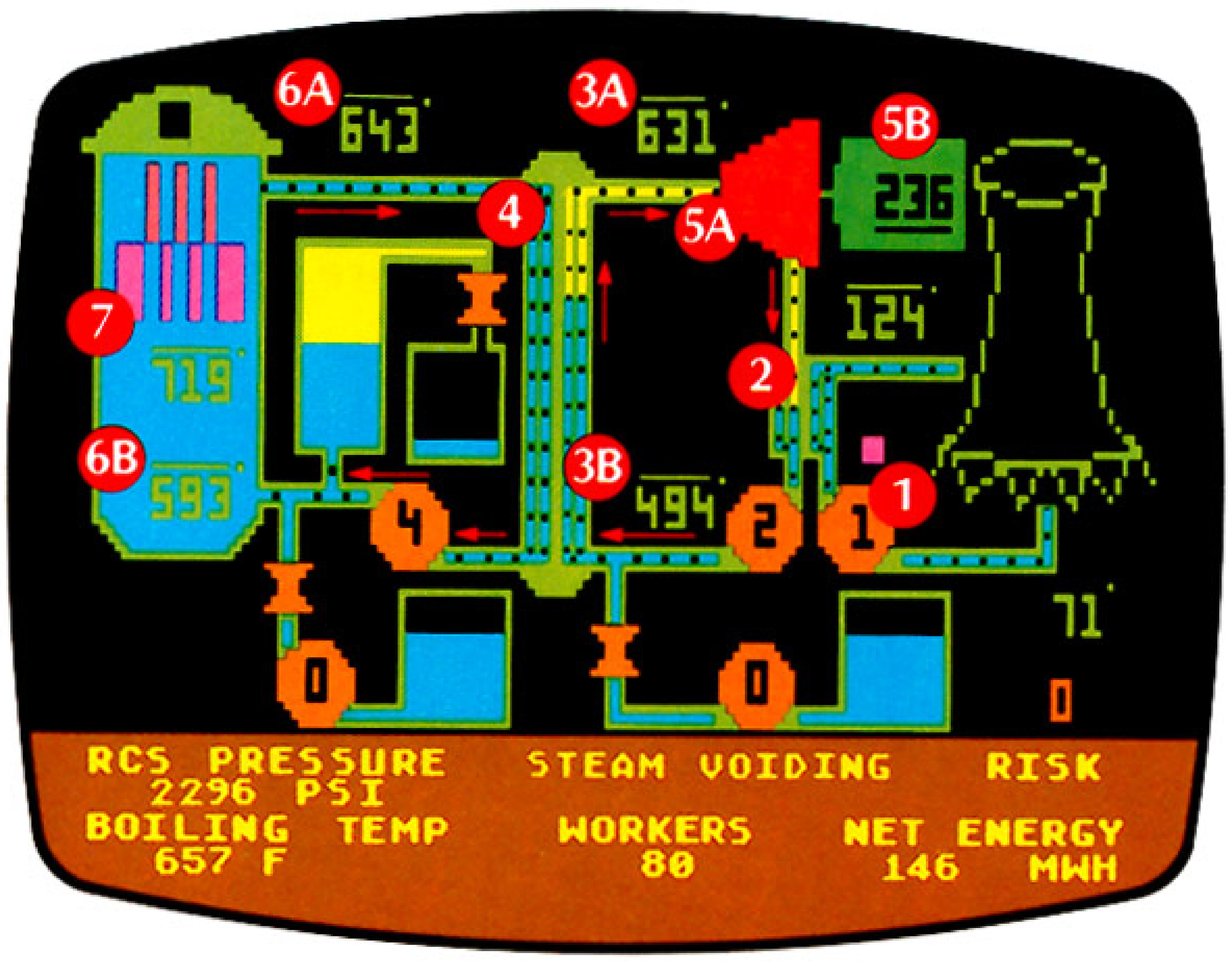


Figure 14. Heat Backup in the Nuclear Power Plant

- Turning off a circulating water pump (1) decreases water flow through the condenser and lowers the thermal conductivity of the Tertiary or Circulating Water Loop.
- In the condenser (2) less heat flows from the steam into the circulating water, and heat backs up in the Main Feedwater System.
- The Main Feedwater System heats up (3A,3B), decreasing the temperature gradient between the RCS and the Feedwater System.
- The RCS water passes less heat into the feedwater flowing through the steam generator (4).
- The feedwater provides less steam for the turbines (5A), so the turbines slow down and less electricity is produced (5B).
- Since less heat is passed into the feedwater, heat backs up in the RCS (6A,6B), reducing the temperature gradient between the RCS and the reactor core.
- The core releases less heat into the RCS water and grows hotter (7).

PRESSURE PRINCIPLES OF THE SIMULATION

PRESSURE AND BOILING POINT

Are you wondering why the water in the Main Feedwater System boils into steam in the steam generator but the water in the reactor vessel does not? Everybody knows that the boiling point of water is 212 degrees Fahrenheit, and the temperature of the water in the reactor vessel is a good deal higher than that. Why doesn't the water boil?

The answer is the water pressure. The boiling temperature of water depends upon the pressure.

The higher the pressure, the higher the boiling point.

The water in the Main Feedwater System is kept at a pressure of about 1000 psi. At this pressure the boiling point is about 550 degrees Fahrenheit. Since the feedwater in the steam generator becomes hotter than this, it boils into steam.

We want the feedwater in the steam generator to boil into steam because steam turns the turbines much better than water. But we do not want the water in the reactor vessel to boil. We keep the water in the RCS at a pressure between 2200 and 2300 pounds per square inch (psi) so that the boiling temperature will be around 655 degrees Fahrenheit. (The RCS pressure and boiling temperature appear in the text window; see Figure 2.) This temperature is hot enough for maximum heat transfer to the turbines but low enough to prevent water around the reactor core from boiling into steam. If steam bubbles form around the core, steam voiding will start...a very dangerous condition.

STEAM VOIDING

You experienced steam voiding when you turned off the RCS pumps in order to melt the core. Remember that the **STEAM VOIDING!** warning flashed and the alarm sounded. What happened was this: When you turned off the RCS pumps, you decreased the flow of water around the core. This decreased thermal conductivity, and the reactor core retained heat. In a short time the core was hot enough to boil the water around it into steam.

You know that when water in a pan starts to boil, steam bubbles form first in the bottom layer of water, the layer closest to the source of heat. The same thing happened in the reactor vessel. Steam bubbles formed in the layer of water around the core. Since steam is a very poor conductor of heat, it acted as an insulating blanket, preventing the core from releasing heat into the water. In a little while the reactor core was hot enough to melt down.

Steam voiding happens whenever you shut down a water pump in one of the loops. It can be an RCS pump, a feedwater pump, or a circulating water pump. Turning off one of these pumps reduces water flow, which reduces thermal conductivity and causes heat to back up to the reactor. The reactor core heats up very fast when you turn off a circulating water pump, less fast when you turn off a main feedwater pump, and moderately fast when you turn off an RCS pump.

HOW TO CONTROL STEAM VOIDING

If steam voiding occurs, you will have to act promptly to stop it. Not only do you have to prevent a meltdown, you also have to keep the turbines turning. The generators cannot continue to generate electricity if insufficient heat is transferred to the turbines.

There are two ways to control steam voiding:

- Increase RCS pressure and boiling point by pumping additional water from the HPI into the reactor vessel.
- Decrease nuclear power output by lowering the control rods into the reactor core.

The sooner you act, the easier it will be to stop steam voiding. Open the HPI valve and turn on the HPI pumps. Lower the control rods partway into the core. If necessary, scram the reactor. Eventually the turbines will stop turning altogether and electricity output will drop to zero. But that will not end your problems. You must continue cooling down the reactor core until steam voiding stops.

WHEN PRESSURE IS TOO HIGH

The high pressures we use to stabilize the heat transfer system and generate electricity must not fluctuate, and they must not be allowed to get too high. Fluctuations or "pressure transients" are sudden surges of pressure. If they exceed 3000 psi, they can generate something like water hammer on a gigantic scale. Seals, valves, and even pipes can blow and cause a loss of coolant accident (LOCA) in the RCS.

LOCA

If LOCA happens and the RCS starts to leak, you will know it. The RCS reading in the text window will suddenly plunge and steam voiding will start. You must act fast when you see this. Turn on all four HPI pumps and hope that you can pump water into the pressure vessel faster than it can escape through the blown holes. Scram the reactor too; it will heat up fast. A better solution is to prevent LOCA by keeping the RCS pressure well below 3000 psi.

THE PRESSURIZER

The pressurizer helps keep the RCS pressure at the right level by generating a steam bubble that "cushions" pressure transients. When pressure is normal, the pressurizer is half steam bubble and half water. If the pressure is too high, the pressurizer contains mostly water; if pressure is too low, it contains mostly steam bubble.

If there is too little steam bubble, the pressurizer is in danger of becoming "water solid" (all water). A water-solid pressurizer is useless. Any pressure transient that comes along could easily damage the RCS. To prevent the pressurizer from becoming water-solid, heaters inside the pressurizer turn on automatically and boil some of the water into steam to increase the size of the steam bubble.

If the RCS pressure rises above 2400 psi, you must open the pressure relief valve (PRV) and let steam escape into the quench tank. This will lower the RCS pressure. Close the valve when the RCS pressure falls to normal levels (between 2200 and 2300 psi) and the pressurizer is about half water, half steam bubble. Do not forget to close the PRV, or the water level in the pressurizer will rise again and RCS pressure will drop too low.

WHEN PRESSURE IS TOO LOW

Too low a pressure in the RCS decreases thermal conductivity and temperatures start to rise. At the same time, the drop in pressure reduces the boiling point of the RCS water. The combination of a temperature increase and a decrease in RCS boiling point will cause what? That's right...**steam voiding**.

POWER STATION INDICATORS

Temperature, pressure, power output readings, and the water levels in the tanks tell you whether the plant is behaving normally or not. Your ability to read and interpret the indicators can make the difference between passing or failing your qualifying exam, the SCRAM game. The indicators are shown in Figure 15.

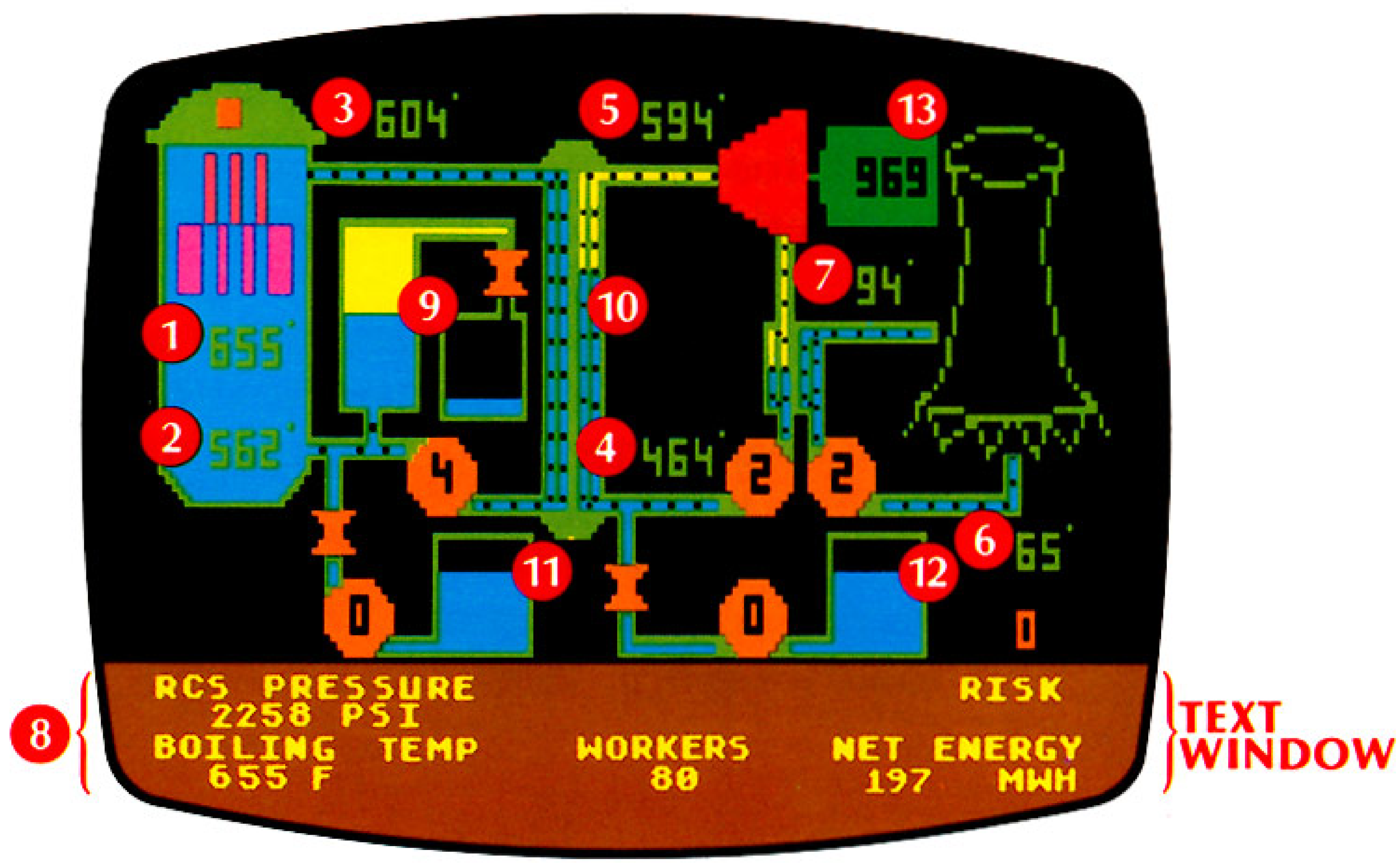


Figure 15. Nuclear Power Station Indicators

1. Reactor Temperature
2. RCS Cold Leg Temperature
3. RCS Hot Leg Temperature
4. Feedwater Cold Leg Temperature
5. Feedwater Hot Leg Temperature
6. Circulating System Cold Leg Temperature
7. Circulating System Hot Leg Temperature
8. RCS Pressure and Boiling Temperature
9. Pressurizer Steam/Water Level
10. Steam Generator Steam/Water Level
11. HPI Water Tank Level
12. Auxiliary Water Tank Level
13. Generator Power Output

TEMPERATURE

REACTOR TEMPERATURE

The temperature of the reactor (the core and the RCS water at the skin of the core) is shown between the RCS water inlet and outlet temperatures in Figure 15. Reactor temperature decreases when the control rods are lowered and increases when the rods are raised.

If an RCS, main feedwater, or circulating water pump fails or is turned off, heat transfer is reduced, heat backs up to the core, and reactor temperature rises. How fast the temperature rises depends upon the pump. Loss of a circulating water pump or a feedwater pump causes the temperature to rise faster than loss of an RCS pump. When the reactor core heats up enough to boil the water around it, steam voiding starts.

LOOP TEMPERATURES

Each loop in the heat transfer system has two temperature readings: a cold leg or inlet temperature reading, and a hot leg or outlet temperature reading (see Figure 15).

In all loops, both hot and cold leg temperatures fall when the control rods are lowered into the reactor core and rise as the rods are raised out of the core.

Loss of an RCS, main feedwater, or circulating water pump reduces thermal conductivity, which decreases heat transfer. In the immediate loop the first reaction is a drop in the cold leg temperature and a rise in the hot leg temperature. Then both temperatures increase as the temperature gradient improves. Temperatures rise in the immediate loop and in all loops back to the reactor as heat backs up through the system to the reactor core.

RCS PRESSURE AND BOILING POINT

The RCS pressure and boiling temperature indicators are in the text window of the simulation (see Figure 15). The boiling temperature increases and decreases with the pressure.

Normally, RCS pressure increases and decreases with reactor temperature. If the temperature rises, RCS pressure increases. If the temperature drops, RCS pressure decreases.

If RCS pressure rises above 3000 psi, the overpressure will cause a loss of coolant accident (LOCA). To reduce the RCS pressure and prevent LOCA, lower the control rods to cool the core and open the PRV to let steam escape into the quench tank.

If RCS pressure drops too low, the RCS boiling point decreases while reactor temperature increases. Soon steam voiding starts. A drop in RCS pressure results from an open PRV or a leak in the RCS.

NOTE: If the HPI valve is not closed after the HPI pumps are turned off, water will leak through the valve, RCS pressure will drop, and steam voiding will start.

To stop steam voiding, pump water from the HPI into the reactor vessel to increase RCS pressure and boiling point, or lower the control rods to reduce reactor temperature. If reactor temperature is very high, you may have to use both techniques.

WATER LEVELS

STEAM GENERATOR

The ratio of steam to water in the steam generator tells you whether sufficient feedwater is entering the steam generator. If you lose a feedwater pump, the water level falls. If you pump in water from the Auxiliary Feedwater tank, the water level rises.

NOTE: If the auxiliary feedwater valve is not closed after the water pumps are turned off, feedwater will leak through the valve and the water level in the steam generator will drop. This will lower pressure, reduce heat flow, cause heat backup, and bring on steam voiding.

HPI AND AUXILIARY FEEDWATER TANKS

The water level in these tanks will drop when the valves are open and the pumps are turned on.

GENERATOR OUTPUT

The amount of electricity being generated is shown in the green rectangle that represents the generator (Figure 15). Generator output is measured in megawatts.

If heat transfer is normal and steam voiding does not occur, the generator output increases and decreases with nuclear power output. If you lower the control rods, less heat flows to the turbines and the turbines slow down. If you raise the rods, heat flow increases and the turbines speed up.

If steam voiding occurs, generator output decreases and eventually stops altogether as less and less heat flows to the turbines.

PRACTICE RUN

Now go back and run the simulation again. This time see if you can predict the response of the nuclear power station as you lower the control rods, turn pumps on and off, and open and close valves.

8

THE SCRAM GAME

SCRAM tests your ability to keep the plant running under very adverse conditions. The object is to generate as much electricity as possible and shut down the reactor before the core melts down. Sounds simple? Wait and see the risks you have to take. We have arranged for earthquakes to come along and break one component after another. You have to find and fix the broken components and keep on generating power until you run out of workers to make repairs. Then you must decide when the time has come to shut down the reactor.

SCORING

Your score is the number of megawatt hours (MWH) of net energy you produce before shutdown. It is displayed by the **NET ENERGY** counter in the lower right corner of the text window. In the back of this manual we have provided a **SCORECARD** so that you can keep track of your score.

QUALIFYING AS AN OPERATOR

Your ability to qualify as an operator depends upon how much net energy you can generate before shutdown and the amount of risk you take doing it. The risk is earthquake damage. The more risk, the more earthquakes, and the more damage. There are nine levels of risk. If you succeed in generating 300 MWH of energy at RISK 9, you qualify as a REACTOR OPERATOR and win a job in our nuclear power plant. If you generate as much as 500 MWH of energy at RISK 9, you become a SENIOR REACTOR OPERATOR, which is as high as you can go. So far only two people in our Silicon Valley Nuclear Power Plant have succeeded in making Senior Reactor Operator. Maybe you'll be the third one.

IF YOU MELT THE REACTOR CORE

If you melt the core, you fail your exam. Do not count the net megawatt hours of electricity generated; your score is ZERO. However, we'll give you another chance. Start the game over again at the same RISK level.

HOW TO PLAY

There are five steps in the SCRAM game:

1. Build a new nuclear power plant.
2. Advance the RISK level.
3. Find the earthquake damage.
4. Send in the workers.
5. Shut down the reactor.

BUILD A NEW PLANT

You will need a brand new Silicon Valley Nuclear Power Station to play SCRAM. Melt down the reactor core and get rid of your station if you have been experimenting with it. This is the last time you will be allowed to melt the core without penalty, so make the most of it.

NOTE: The fastest way to melt the core is to turn off both feedwater pumps or both circulating water pumps.

After meltdown, press START to build a new station. We'll wait for you.

Ready?

Now look at the **RISK** digit. It's the orange zero in the lower right corner of the simulation.

ADVANCE THE RISK LEVEL

Right now the RISK digit reads 0 because you aren't taking any risk. To start the game, you must advance RISK to a number from 1 to 9. The higher the number the more earthquakes you will have and the more damage you will have to repair. We'll tell you how to advance RISK later on. Now let's talk about earthquake damage.

FIND THE EARTHQUAKE DAMAGE

How will you know when an earthquake strikes? Don't worry, you'll know. Just don't try to adjust your television set.

Right after the tremor, you will hear the sound of something breaking. This will be either a pump or a valve, but which one? They will all look and act normal. Pumps will turn on and valves will open. Nevertheless, some pump or valve is definitely broken. Every earthquake breaks something. You should try to find the damage quickly before another quake strikes and breaks another component.

How can you find a broken valve or pump if they all look and act normal? You'll have to rely on the indicators. If you got good marks in Thermodynamics 1A and know how to read the indicators, you should be able to deduce which component is broken. Observe the changes in temperature, pressure, and power, and look at the water levels in the steam generator, pressurizer, and water tanks.

For example, suppose you try to open the PRV to reduce RCS pressure. It looks as if the PRV opens and steam flows into the quench tank, but looks can be deceiving. The sure test is the water levels in the pressurizer and the quench tank. If the water is not rising, then the PRV is damaged and cannot be opened.

Here is a helpful bit of information: A pump cannot break unless it is turned on. A valve can break whether it is open or closed.

SEND IN THE WORKERS

When you think you have deduced which valve or pump broke, move the cursor to it. Press the red button on the Joystick and move the Joystick to the right of left. Now watch the text window. It will either flash **RIGHT!** or **WRONG!**.

Whether you are right or wrong, whenever you select a component, five of your **80 WORKERS** go into the plant to fix it. You won't see them working in the plant. You'll just have to take our word that they are on the job. If you picked the right component, the workers will fix it immediately. You won't see or hear any repairs being made, but you can take it for granted that the component is fixed. Of course, once a component is fixed another earthquake may come along and break it again. Earthquakes are unpredictable.

If you picked the wrong component, your workers will still go in to repair it, but of course they won't find any damage. In effect, you will have wasted five workers.

None of the workers you send in will return to work. The Nuclear Regulatory Commission has very strict rules about the amount of radioactivity each worker can be exposed to per quarter. Those you send into the plant will have had the maximum exposure and won't be back for three months. In the meantime, you have fewer workers to make repairs. The number of workers that remain is shown by the WORKERS counter in the middle of the text window.

When all 80 workers are gone, you have had it. If you try to send in workers when there aren't any, the text window will flash **NO WORKERS!** So do not commit your workers to repair a valve or pump unless you are pretty sure you know which one is broken. On the other hand, if you take too long to make up your mind, damaged components may pile up and the reactor core may melt down.

SHUT DOWN THE REACTOR

While your ultimate goal is to generate as much net energy as possible, it should be obvious that you can't go on forever. Eventually you will run out of workers and there will be no way to make repairs when more pumps and valves break. Then its meltdown time...UNLESS you shut down the reactor first. Part of the qualifying exam is a test of your ability to judge the right time to quit generating power and start shutting down.

When you think the time has come, lower the control rods into the core and start cooling it down. If you get the reactor temperature below 200 degrees Fahrenheit, you will achieve **COLD SHUTDOWN**, and the game is over.

NOW YOU PLAY

Move the cursor down to the RISK digit and advance it to level 1 with the Joystick. You change the RISK level the same way you turn on a pump or open a valve: Hold in the red button and push the Joystick straight up. If your score at RISK 1 is at least 1000 MWH of energy, advance to RISK 2. Keep on advancing until you are up to RISK 9. The SCORECARD in the back of the manual gives you a good idea of when your score is high enough to advance to a higher RISK level.

NOTE: Every time you advance the RISK level, the NET ENERGY counter returns to zero.

9

HOW TO SUCCEED AT SCRAM

Would you like to improve your score? Here are some helpful hints.

KEEP THE MAIN WATER PUMPS GOING

The optimum strategy in SCRAM is to keep the reactor core generating maximum power as long as possible. To do this you must keep all the vital water pumps running. Loss of a vital pump will force you to lower power output and will narrow your margin of safety. This is especially true if you lose a main feedwater or circulating water pump, since there are only two each of these pumps. If you lose an RCS pump you may have to cut back on reactor power a bit, but you will not be hurt very much.

READ AND INTERPRET THE INDICATORS

To determine whether an RCS, main feedwater, or circulating water pump failed, read the cold and hot leg temperatures in each water loop. If a loop shows a rise in hot leg temperature and a drop in cold leg temperature, you know that a pump in that loop has failed.

Pump failure is also indicated by water levels. For example, if the water vs. steam level in the steam generator drops below normal, you know that less water is entering the steam generator and can deduce that a feedwater pump has failed.

Failure of a vital pump will lower thermal conductivity generally and reduce electricity output. However, do not be confused if power does not drop immediately after a vital pump fails. Remember that all the indicators reflect physical processes that have a natural inertia of their own. The generator may continue to produce power for a little while after the pump fails, but power output will drop in time.

The easiest way to diagnose failure of the HPI or Auxiliary Feedwater System is to look at the water levels in the tanks. If the system is supposedly operating but the water level never drops, either the valve is broken or all the pumps have failed. A broken valve is more likely, but if you have had many earthquakes, it's possible that all the pumps are broken.

You can also tell whether the HPI is working by looking at the pressurizer and the RCS pressure indicator in the text window. If the HPI is operating, the RCS pressure should rise and the water level in the pressurizer should increase. Similarly, you can tell if the Auxiliary Feedwater System is working by looking to see if the water level in the steam generator rises when auxiliary feedwater is pumped into the steam generator.

A REMINDER: A pump that is not turned on cannot be broken.

TRY THE VALVES

If a valve breaks by sticking closed, you may not be able to spot the damage by reading the indicators. You may not know the valve is broken until some time later when you try to open it. If you suspect a valve has stuck closed, see if it works as it should. Does the water level in the tank rise or lower as it's supposed to? If not, the valve is broken.

KEEP A RECORD OF THE DAMAGE

Remember that every earthquake breaks a valve or a pump, and you have to fix each one. It will probably help to keep track of the number of times items break, the breakage you fix, and the breakage you do not fix. Remember also that a component that is repaired can break again.

APPENDIX

ACCURACY OF THE SIMULATION

SCRAM is a highly sophisticated nuclear power plant simulation; however, like any simulation it is a simplified model of the real thing. A real nuclear power plant is immensely more complex. For example, it usually has some 500 miles of piping, two steam generators, four turbines, four generators, and several hyperbolic cooling towers.

In our effort to simplify the model, we have left out many safety features of a real nuclear power plant and may have unintentionally biased the simulation. For example, a real nuclear power plant has an important system called the Emergency Core Cooling System (ECCS). This system consists of at least three independent subsystems, all of which provide additional water to cool the reactor core in case of an emergency. We have included only one of these subsystems, the High Pressure Injection System or HPI.

We have also left out the containment building, the huge concrete structure that houses the reactor. It is designed to contain radioactivity in the event of a meltdown. The containment building is strong enough to withstand the stresses of the majority of meltdown scenarios. While a meltdown would destroy a nuclear power plant, the chance that it would release sufficient radiation to harm many people is very small.

In order to give you full control over our nuclear power plant, we left out all the automatic safety systems. A real nuclear power plant fairly bristles with automatic safety devices. These systems trigger shutdown at the first sign of trouble and are very effective.

Another unfair element of SCRAM is the suggestion that a nuclear power plant is unsafe in an earthquake. At RISK level 9 you can wipe out every pump and valve in less than 5 minutes. Real pumps and valves are not that delicate. The NRC requires that all critical pumps and valves be able to withstand the worst earthquake that could be expected to occur at the site.

Finally,the speed at which events occur in our nuclear power plant is unrealistic. You can go from "situation normal" to meltdown in less than 2 minutes. There is no way a reactor core could melt that fast. A more accurate estimate is 6 hours. Knowing that you would not want to wait 6 hours for something to happen, we took the liberty of speeding up the time to meltdown.

THE ACCIDENT AT THREE MILE ISLAND

This account of the accident at Three Mile Island is derived from the following publications:

1. **Investigation into the March 28, 1979 Three Mile Island Accident** by Office of Inspection and Enforcement, Investigative Report No. 50-320/79-10; Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington D.C. (August 1979).

2. **Report of the President's Commission on the Accident at Three Mile Island**, John G. Kemeny, Chairman; Washington D.C. (October 1979).

In the following account of the accident, the President's Commission is referred to as the "Kemeny Commission" or "the Commission," and the Commission's report is referred to as the "Kemeny report."

The accident occurred at 4 AM on Wednesday, March 28, 1979. A faulty valve closed, cutting off the supply of water to the main feedwater pumps and forcing the pumps to shut down. When the feedwater was cut off, the water in the steam generator began to boil away. The reactor scrammed automatically, and the auxiliary feedwater pumps turned on automatically. However, the Auxiliary Feedwater System failed to operate because someone had closed the block valves on the pumps...a very serious violation.

With absolutely no water in the Secondary Loop, the Primary Loop heated up rapidly, and the RCS pressure rose. The increase in pressure caused the pressure relief valve (PRV) to open and vent steam from the pressurizer. When the RCS pressure stabilized, the PRV tried to close but stuck open. To compound the problem, the indicator in the control room showed that the valve had closed.

Water from the RCS poured through the open PRV into the quench tank, and the RCS pressure fell rapidly. The pressure drop automatically triggered the HPI pumps, which began pumping water into the reactor vessel. As the RCS pressure increased, the water level in the pressurizer began to rise. When the operators saw this, they thought the HPI pumps were pumping in too much water and turned them off to prevent the pressurizer from going water-solid. This was the worst thing they could have done.

Without cooling water, the reactor temperature skyrocketed. At about 2300 degrees Fahrenheit, the zirconium in the fuel cladding reacted with the steam and corroded the fuel rods. The fuel rods began to disintegrate, releasing hydrogen gas and intensely radioactive material into the RCS water. The gas and radioactive matter were carried by the water through the open PRV into the now ruptured quench tank and thus entered the containment building.

Around 1:50 PM Wednesday, the hydrogen gas in the containment building exploded. The explosion caused no damage, but it frightened a lot of people. Fear was intensified by news reports on the following Saturday that the NRC was investigating the possibility of a hydrogen explosion inside the reactor. According to the Kemeny report, these fears were groundless:

"The great concern about a potential hydrogen explosion inside the TMI-2 reactor came with the weekend. That it was a groundless fear, an unfortunate error, never penetrated the public consciousness afterward, partly because the NRC made no effort to inform the public that it had erred." (Kemeny report, page 126)

The radioactive RCS water seeping from the ruptured quench tank into the containment building was automatically pumped into radioactive-waste storage tanks in the auxiliary building. Soon these tanks overflowed, allowing radioactivity to escape into the auxiliary building and from there into the environment. Had operators thought to shut down the pumps, the radioactivity could have been confined to the relatively safe containment building and the release into the atmosphere would probably not have occurred.

By Wednesday evening, March 28th, the crisis within the plant had subsided. The mistakes of the morning had been found and corrected. Water was flowing, the system was stable, and the long, slow, and delicate process of cooling the system down had begun.

Outside the plant, the crisis was prolonged by conflicting assessments of the danger, misinformation, and uncertainty about what to do next. The Kemeny Commission reported: "We found that the mental stress to which those living within the vicinity of Three Mile Island were subjected was quite severe....Throughout the first week of the accident, there was extensive speculation on just how serious the accident might turn out to be. At various times, senior officials of the NRC and the state government were considering the possibility of a major evacuation....On Friday a mistaken interpretation of the release of a burst of radiation led some NRC officials to recommend immediate evacuation....On Saturday and Sunday, other NRC officials mistakenly believed that there was an imminent danger of an explosion of a hydrogen bubble within the reactor vessel, and evacuation was again a major subject of discussion." (Kemeny report, page 13)

The Kemeny Commission concluded that "...the most serious health effect of the accident was severe mental stress, which was short-lived." (Kemeny report, page 13)

The effect of the radioactivity released into the environment was assessed by the Commission as follows: "It is estimated that between March 28 and April 15 (1979) the collective dose resulting from the radioactivity released to the population living within a 50-mile radius of the plant was approximately 2000 person-rems. The estimated annual collective dose to this population from natural background radiation is about 240,000 person-rems. Thus, the increment of radiation dose to persons living within a 50-mile radius due to the accident was somewhat less than one percent of the annual background level. The average dose to a person living within 5 miles of the nuclear plant was calculated to be about 10 percent of annual background radiation and probably was less." (Kemeny Report, page 34).

The Commission concluded: "On the basis of present scientific knowledge, the radiation doses received by the general population as a result of exposure to the radioactivity released during the accident were so small that there will be no detectable additional cases of cancer, developmental abnormalities, or genetic ill-health as a consequence of the accident at TMI." (Kemeny report, page 34).

BIBLIOGRAPHY

Investigation into the March 28, 1979 Three Mile Island Accident by Office of Inspection and Enforcement, Investigative Report No. 50-320/79-10; Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington D.C. (August 1979).

Nuclear Power Issues and Choices, Report of the Nuclear Energy Policy Study Group;Ballinger Publishing Co., Cambridge MA (1977).

Nuclear Reactors by John F. Hogerton; United States Atomic Energy Commission, Division of Technical Information, Oak Ridge TN (1974).

Report of the President's Commission on the Accident at Three Mile Island, John G. Kemeny, Chairman; Washington D.C. (October 1979).

"The Safety of Fission Reactors" by Harold W. Lewis; *Scientific American*, Volume 242, Number 3 (March 1980).

Here are some other books you may enjoy reading:

The Health Hazards of Not Going Nuclear by Peter Beckmann; Golem Press, Box 1342, Boulder CO (1976).

Non-Nuclear Futures by Amory Lovins and John Price, Ballinger Publishing Co., Cambridge MA (1977).

SCORECARD

RISK Level	Record Your Score (Net Energy, MWH)	If Your Score Is...
1		1000 MWH pass to Level 2
2		900 MWH pass to Level 3
3		800 MWH pass to Level 4
4		700 MWH pass to Level 5
5		600 MWH pass to Level 6
6		500 MWH pass to Level 7
7		400 MWH pass to Level 8
8		300 MWH pass to Level 9
9		300 MWH **VERY GOOD! YOU'RE A REACTOR OPERATOR**
9		500 MWH **CONGRATULATIONS! YOU'RE A SENIOR REACTOR OPERATOR**