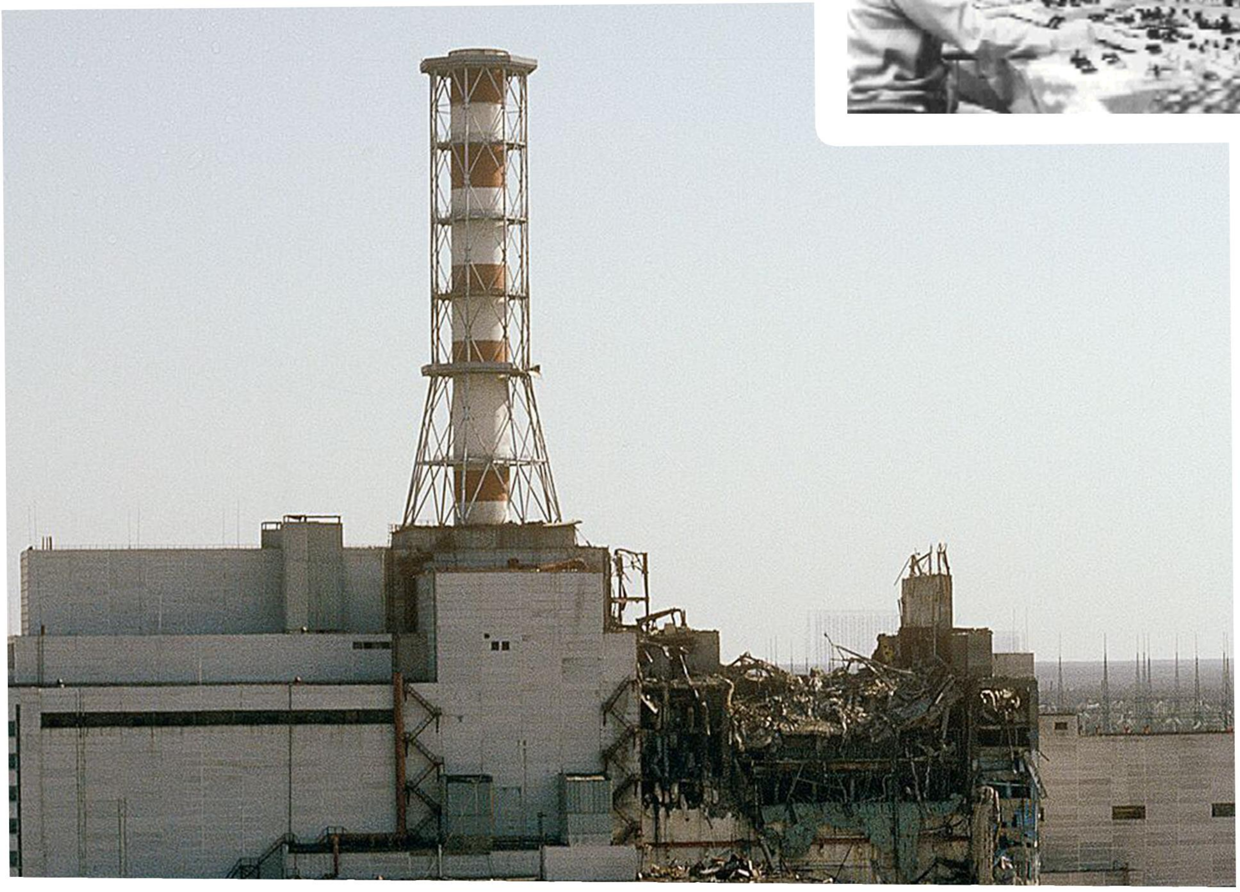
CHERNOBYL

The Legacy Continues...

INFORMATION & USER'S GUIDE



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1.0
System Requirements and Program Installation

The *minimum* system requirements for Chernobyl, The Legacy Continues are:

- Windows® 3.1 with 8 MB of Ram (Windows® 95 and 16 MB or more of ram highly recommended).
- 80486 66 MHz processor (Pentium® recommended)
- 10 MB of free disk space.
- 640 x 480, 256 color VGA graphics (higher resolutions and colors are highly recommended. 1024 x 768, 24 bit color is optimal).
- Quad speed or faster CD-ROM drive.
- Sound Blaster® or compatible sound card with speakers.
- Mouse or other pointing device.

Higher color and resolution than the minimum is recommended due to the number of controls that can be opened on the screen at one time. This software product is designed to operate best in 1024 by 768 resolution and 24-bit color. It also works well in 800 by 600 resolution. If you must use it in 640 by 480 resolution, the screens will be very crowded. It will work, but you will have to make the best use of your space by cascading the windows and learning how to use the right and left mouse keys to your best advantage.

An important tip to remember: The right mouse key brings background graphics to the foreground when you click on a neutral point. Experiment, and learn to use the mouse to your best advantage. Especially if you must run in 640 by 480 resolution.

Installation Guidelines:

Windows® 3.1:

1. Place the CD-ROM in your CD-ROM drive.

2. From the Program Manager menu. select RUN and then type in your CD-ROM drive letter + SETUP.

3. Click OK.

Windows® 95

1. Place the CD in your CD-ROM drive.

2. Click on START (lower left corner of your Windows screen).

3. Click on RUN. This opens a window that allows you to place the letter of CD-ROM drive and a file name. The file that installs Chernobyl is called SETUP. Place the letter of your CD-ROM drive in the data field along with SETUP and press enter. Example: D:\SETUP.

4. The setup program will install Chernobyl in a folder called Chrnobyl. If this is not the folder you wish to place the program files in, setup will prompt you to change it. Once loaded, Chernobyl may be accessed by clicking on the Chernobyl icon located in the programs portion of Windows.

Installation Troubleshooting:

If you encounter problems with the loading or operation of the Chernobyl software, the most common corrections are found below:

1. Chernobyl writes an .ini file during the installation process that tells the program your basic configuration. If you have more than one CD-ROM drive, or if your hard disk drive has multiple partitions, it is possible that this .ini is not directing the program to look for AVI files (movie files) on the correct drive. To correct this, select the NOTEPAD program located in the accessories section of Windows (this can be found by selecting START, then selecting PROGRAMS, and then selecting ACCESSORIES). Once in the notepad program select FILE and OPEN to open the Chrnobyl.ini file. This file is found in the CHRNOBYL directory on your hard disk. When opening a file in notepad, you must select ALL FILES, and not the default .TXT files that appears in the open file menu.

   Once you access the CHRNOBYL.INI file, you must determine what drive the Chernobyl CD-ROM disk will be run from. This drive must be placed on the correct line of the CHRNOBYL.INI file. Below is a sample of the upper portion of the CHRNOBYL.INI file.

   [DRIVES]

   CD ROM DRIVE=D: (This is the line that MUST have the CDROM drive that the Chernobyl CD will run from. If this drive letter is incorrect, you must place the correct drive letter in place of the letter displayed).

   CHERNOBYL GROUP = C\WINDOWS\START MENU\PROGRAMS\CHERNOBYL

   [DIRECTORIES]

   (The .INI file continues from this point).

   Once you edit the .INI file, you must save the file using the notepad save function.

2. If step - 1 above does not correct the problem, and a black movie box appears with no movie displayed, you should reload the Intel IVI4.3 drivers included on the Chernobyl CD. This is completed by selecting the correct folder on the CD (either W31_dvr for Windows 3.1 or 95_dvr for Windows 95) and installing the Intel Indeo 4.3 video for windows drivers. These drivers are installed by changing to the appropriate directory for your operating system and clicking on the installation file. The setup program for the Intel Indeo drivers is SETUP31 for Windows® 3.1 applications and SETUP95 for Windows® 95 applications.

2.0

The Worst Nuclear Accident In he History of the World

At a little after 1:00 AM local time on April, 26, 1986 the worst nuclear accident in the history of the world occurred at the #4 reactor of the Chernobyl Nuclear Power Station. This accident spewed over 200 times the radioactive debris into the atmosphere as the atomic bomb dropped on Hiroshima, Japan in 1945. The Chernobyl Plant is located about 120 miles from Kiev, Ukraine in the former Soviet Union.

This accident was caused by the combination of several items. The first is the grossly flawed design of the reactor used at the Chernobyl Power Station. The Chernobyl reactor design is called an RBMK - 1000. There are 15 other reactors identical to the Chernobyl #4 design still operating in the former Soviet Union including three similar units at the Chernobyl plant site. The Soviet RBMK - 1000 reactors have several unique and chilling characteristics. Five of these characteristics are:

1. They are refuelled during operation. Other than the Canadian CANDU reactor design, they are the only commercial power reactors in the world with this distinction. American Pressurized Water Reactors (PWR's) and Boiling Water Reactors (BWR's) must be shut down to be refuelled. The RBMK - 1000 reactors were designed this way partially because they can be used in one stage of weapons grade uranium enrichment.

2. For economy reasons they use unenriched uranium for fuel. Without going into nuclear physics at this time, using unenriched uranium creates some challenging operating problems. One of which is the inability of the reactor to operate at reduced power ranges for any length of time. This phenomenon is called reactor poisoning. This was one of the factors that contributed to the accident.

3. They are graphite moderated. This is a complex subject, but being graphite moderated also contributed to the accident. Instead of using water as a partial moderator such as the American PWR’s and BWR’s. the RBMK - 1000's use graphite. The combination of the unenriched uranium and the graphite moderation creates a situation where the power level in the reactor core increases when the reactor starts to void. Voiding is a condition where water cooling the core begins to turn to steam. As the water content in the reactor vessel decreases, thus increasing the degree of voiding, the greater the tendency for power to rise in the reactor core. Virtually all of the commercial power reactors in the world experience a power DECREASE when the reactor voids. The RBMK – 1000 experiences a power INCREASE when the reactor voids. This significantly decreases the overall safety of the reactor system.

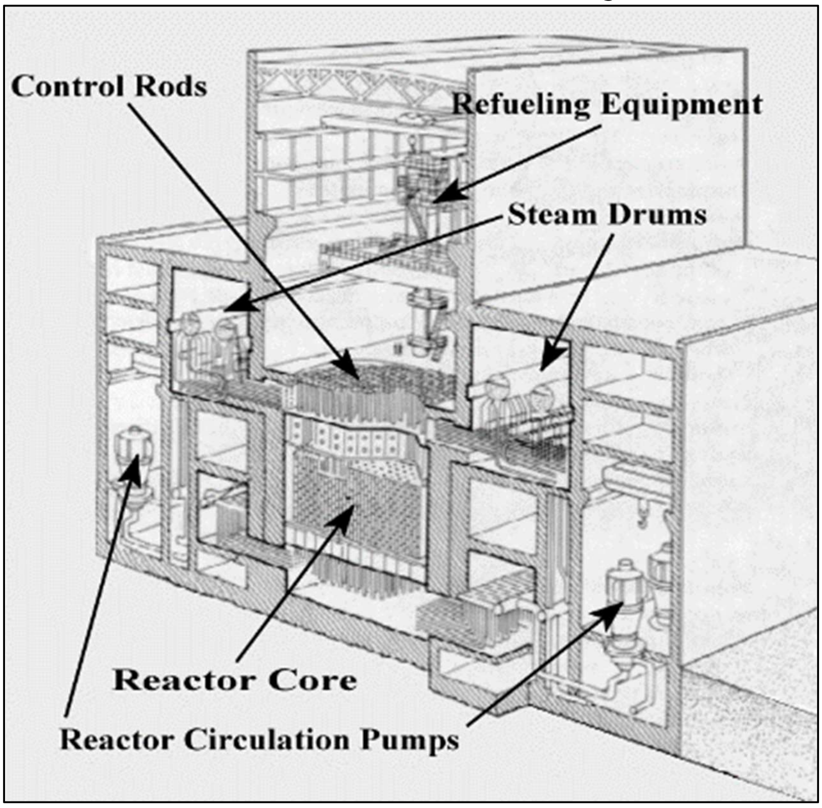
4. The control rods that stop the nuclear chain reaction used graphite “water displacers” on their tips. Since the reactor is moderated with graphite, this causes the reactor power to momentarily increase when the reactor is scrammed. A scram is an emergency shutdown of the reactor core. All commercial power reactors, with the exception of the RBMK, are designed to insert the control rods and stop the nuclear chain reaction in less than 3 seconds. The RBMK's take over 30 seconds to fully insert the control rods and stop the nuclear chain reaction. This slow movement of the control rods, combined with the graphite tips causing a momentary increase in power, all aided in the accident.

5. The Soviet RBMK - 1000 reactors do not use a containment structure. This alone would have greatly reduced the severity of the Chernobyl accident. American reactors are housed in pressure sealed containment vessels designed to contain radioactive components in the event of an accident such as Chernobyl. These containment structures are expensive and significantly increase the construction time of a new plant. The Soviets made the decision to not house their reactors in a sealed containment vessel.

The lack of containment, when accompanied by the other listed items and mixed with poor operating practices, caused the death of 31 personnel on the night of the accident.

It also caused untold damage to the environment. Since the accident, the incident of cancer and birth defects in the path of the debris trail is staggering. The atmospheric debris trail stretched from the eastern portion of the Ukraine all the way across Europe, and half way around the world.

Design of the RBMK - 1000 reactor is sited as a major factor in the accident. However, it was not the sole factor. Human error, gross human error, was a major contributor to the accident. With all of its design shortcomings, the RBMK - 1000 reactor has numerous safety systems to prevent an accident from occurring. These safety systems, like all commercial power generation reactors, are designed to override the operator to protect the plant from problems that could lead to loss of radiation. These systems are not effective if shut-down or removed from service by the operators. These very protection systems were, indeed, taken out of service at Chernobyl during a test.



Cross Sectional View of RBMK-1000 Reactor

Ironically, it was during a test of the final and most critical reactor coolant backup system that the reactor exploded. This test, called a rolling inertia test, was designed to see how long the inertia of the turbine generator would continue to supply operating power to the reactor feed and circulation pumps.

The turbine generator sets at the Chernobyl plant are extremely large. They are rated at 1000 megawatts electrical. The weight of the rotor in the turbine and generator is several hundred tons. When there is insufficient steam to keep the turbine generator at rated speed (3,600 RPM in America) the turbine and generator can take up to three (3) hours to come to a stop when rolling down from rated speed.

The rolling inertia test keeps the turbine generator connected to the critical reactor coolant systems. The weight of the turbine and generator rotors act like a massive flywheel. This flywheel, or rolling inertia, uses the stored energy contained in the turbine/generator sets to keep the pumps spinning and pumping.

The grossly flawed procedure designed to test the rolling inertia specified that the emergency reactor cooling systems be removed from service. This included the emergency diesel engine backup systems. With these systems manually removed from service, no backup protection existed on the reactor. The reactor power was reduced to a low value to begin the test. Unfortunately, as we covered earlier, the RBMK - 1000 reactor is not designed to operate at less than 80% power. When the power was reduced to far below this level, the reactor "poisoned-out". This simply means that the radioactive compounds that inhibit a neutron reaction increased beyond the reactor core's ability to maintain the nuclear chain reaction. The reactor essentially was dying a slow nuclear death.

When this type of reactor poisons-out, the accepted operating practice is to shut the reactor down and allow the "poison" compounds to decay in the system. Once they decay, (usually about 24 hours) the reactor can be restarted. A simple solution to a simple problem. However, the operators at the Chernobyl plant did not want to completely shut down the reactor because the test would have been a failure. Therefore, they broke a cardinal rule of RBMK - 1000 operation. The operators removed all of the neutron inhibiting control rods from the reactor core.

It is important to understand that the nuclear reaction in the core is controlled by regulating the number of control rods in the core. When the control rods are all inserted into the reactor's core, the neutrons that create the nuclear reaction are prevented from doing so because they are absorbed or inhibited.

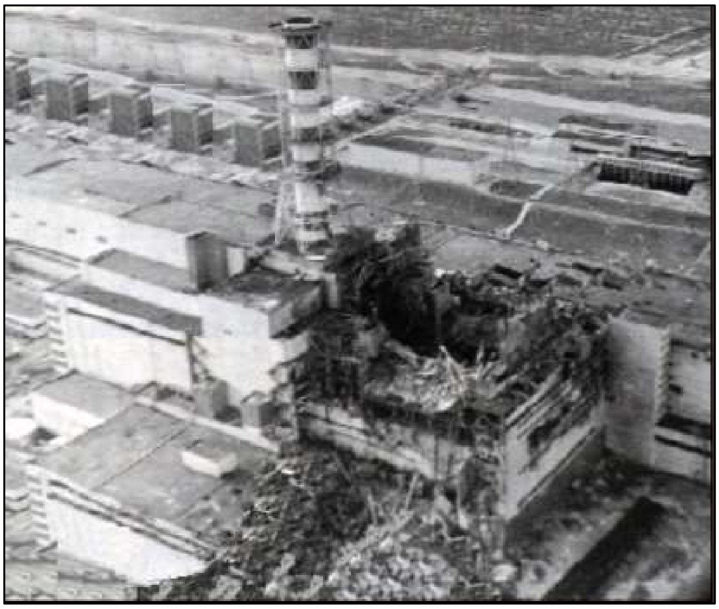
As you remove the control rods from the core, the number of available neutrons is increased, and the nuclear chain reaction starts or increases. As free neutrons are made increasingly available by removing more rods from the core, the temperature in the core increases rapidly.

When the reactor poisoned-out, the operators did not shut it down to allow the poison compounds to decay out. Instead they removed all of the control rods from the core to force the reaction to occur amidst the poison compounds. This, combined with all the emergency backup systems being removed from service, was a truly fatal error.

Seconds before the explosion, the operator realised that he had made a terrible error and pressed the AZ-5, or scram button to insert the control rods, shutting down the reactor. Unfortunately, as we stated earlier, the control rods are extremely slow in the RBMK and the graphite “water displacer” tips actually cause an increase in the core power before stopping the nuclear chain reaction.

The reactor’s power increased sharply causing much of the water cooling the core to turn to steam. This is called voiding the reactor. As discussed earlier, when the RBMK reactor core voids, the power increases instead of decreases. This in turn causes more steam to form, which causes another increase in power. This exponential increase of power in the RBMK caused a massive tube rupture in the cooling system which resulted in a large steam explosion.

After the steam explosion occurred and the cooling system completely failed, the outer covering (or cladding) of the fuel elements began to melt.



Overhead View of the Carnage

This caused the fuel to catastrophically increase in temperature. The superheated steam reacted with the alloy in the fuel cladding, causing hydrogen to form. The hydrogen then caused a second explosion. This massive release of energy set the graphite core on fire.

It is estimated that in a period of 9 seconds the reactor's power output increased to 120 times of normal maximum. The rated thermal output of the RBMK is 3000 megawatts. This means that in 9 seconds the power in the reactor increased to 3,600,000 megawatts or 3.6 gigawatts. In terms of horsepower, this was approximately 4,825,728,000 unconstrained horsepower! Needless to say, the reactor exploded.

Due to the dismal political structure in the former Soviet Union at that time, the authorities at the plant would not acknowledge that an accident occurred. They kept pumping water into a non-existent reactor! The Plant Manager actually sent two different people to their death by insisting they go physically check the reactor. Each person received a lethal dose of radiation, came back and reported that the reactor did not exist. The Plant Manager still did not accept their word.

The local citizens living in the area of the Chernobyl Plant were not even evacuated for over a day after the initial explosion. The rest of the world did not know that an accident occurred until workers at a nuclear plant in Sweden kept setting off radiation detectors after going outside to work. This prompted an investigation that eventually lead to the discovery of the Chernobyl accident.

The Chernobyl #4 reactor was eventually sealed in a massive concrete sarcophagus to stop the graphite fires and prevent the bleeding of radioactivity to the environment. The remains of the accident will be highly toxic for hundreds of years. The sarcophagus is continuously monitored to ensure that it is not leaking radiation. Should the sarcophagus fail, the environment would again be exposed to large amounts of unconstrained radiation.

Ironically, the remaining three (3) reactors at the Chernobyl plant have been restarted. This is because of the severe financial desperation of the former Soviet republics. The terrifying aspect of this is the question of whether or not they have the financial means to properly operate and maintain the other 15 reactors still in service.

Unfortunately, lessons from the Chernobyl accident are still being learned today. The death rate from different types of cancers and the birth defect rate in the main radiation path after the accident are many times above normal. Even now scientists are studying the effects of the radiation on the people and the environment to determine the severity of this accident. Have we applied what we have learned at Chernobyl to prevent the accident from being repeated?

Authorities in the former Soviet Union insist that they have undertaken a major training effort to prevent a repeat of the accident. They say that they now require strict adherence to established operating procedures. The graphite "water displacer" tips on the reactor control rods have been removed to facilitate reactor scrams.

As far as the most major design flaws in the RBMK - 1000 system, they cannot be mitigated. The reactors will remain unsafe and vulnerable to accidental discharges (possibly massive) of radioactive material as long as they are in operation.

Though packaged as a game, the simulator portion of *Chernobyl, The Legacy Continues* is a very accurate emulation of the RBMK reactor and the dangers they pose. We have somewhat simplified its operation by removing many of the subsystems to allow a non-technical user to understand the main components of the operation. However, the overall operation is very accurate. This allows the user to experience what operating the Chernobyl plant would actually be like. See if you can make the necessary decisions and keep the reactor operating as it should. Good luck! You are definitely going to need it.

3.0
Chernobyl File and Menu Basics

Anytime the Chernobyl program is initiated, a file called an Initial Condition File (always referred to as an IC file) is loaded. This file contains the data that starts the Chernobyl program at a preset point. This is the case at the beginning when you choose the level you wish to operate in. When you choose Plant Operator, Shift Supervisor, Chief Engineer, or Plant Manager, an IC file loads the critical data so the simulator knows what load, temperature, pressure, etc. each piece of equipment is at. As a user of Chernobyl, you can also easily save your own initial conditions. This allows you to save the state of the simulator at any point in time and return to it later.

To save or restore an initial condition you must first start the program. From within the program you must select the File heading on the pull-down menu in the upper left corner of the screen. When you click on File you will open a menu that says Save and Restore on it. When you select Save a box will open called INITIALIZATION FILES. This box allows you to place a name or number combination in the box that says "Selected File(s)". The name or number that you enter must have .icd on the end of it. An example would be if you were saving the current state of the game under your name and the date, you could put something like this in the box:

Selected file(s) joe91998.icd

You would then click on the Save box. When restoring that particular initial condition, you would click on the File heading, and then select Restore. The same basic box opens as before. The difference is you would use the scroll bar to locate the name of the game you wish to recall or restore. You must click on it to place it in the Selected file(s) box and then click the Restore button. If you know the name of the initialization file you want to load, you can also type it in the Selected file(s) box and click on the Restore button. The scroll bar and file listing box is for your convenience only.

4.0

Quick Overview of a Thermal Nuclear Generating Station

One of the most overused illustrations of how a thermal generating station works is the teapot and pinwheel. However, it is pretty accurate as a simple analogy of a plant. See Figure - 1.

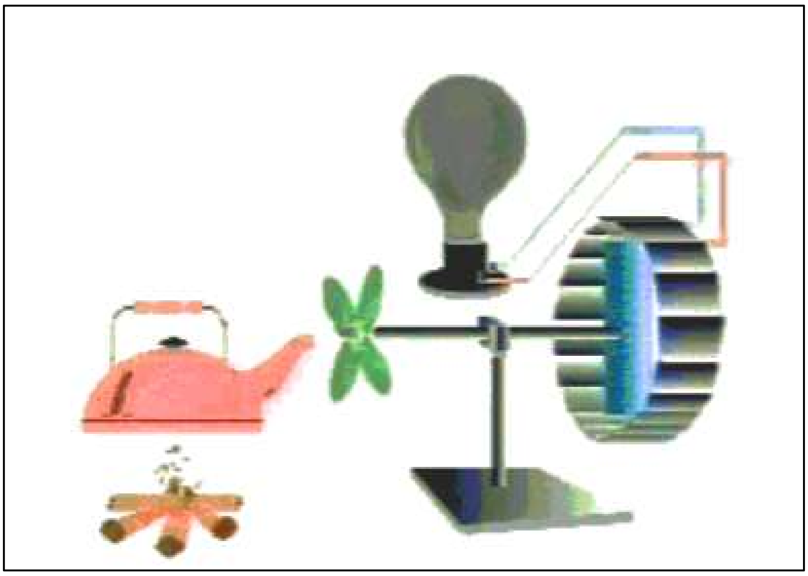


Figure 1 : Basic Tea Kettle Power Plant

The generation of electrical energy by conventional and nuclear sources all share a common element. This common element is heat. By converting the heat from combustion or the splitting of atoms to steam, we can cause a turbine to turn. The mechanical motion of the turbine is then used to turn a generator. The mechanical motion of the generator produces electricity. Figure - 1 illustrates this well. The heat from the burning wood under the tea Kettle produces steam from the spout of the kettle. This steam impacts the pinwheel making it spin. As it spins the generator turns, continuously breaking a magnetic field inside the generator. This produces electricity that lights the light bulb.

A modern nuclear plant is far more complex, but the principles of energy conversion are very similar. Instead of burning wood to create heat that causes the water in the kettle to boil, we create a controlled nuclear reaction.

This reaction creates heat from neutron movements (commonly called *neutron flux*) within the nuclear fuel core. Once we have created heat, the rest of the process is essentially the same. See Figure - 2.

The heat turns water to steam in a boiler or what is commonly called a *steam generator*. The steam flowing from the steam generator impacts on the pinwheel or turbine. As the steam impacts on the pinwheel or turbine, some of the energy in the steam is imparted to the pinwheel turbine. This is a very critical area of understanding. Virtually everything in a modern nuclear plant is part of an energy exchange or conversion process. The energy exchange process in a nuclear plant is:

1. Nuclear to Thermal (In the reactor)
2. Thermal to Mechanical (In the turbine)
3. Mechanical to Electrical (In the generator)

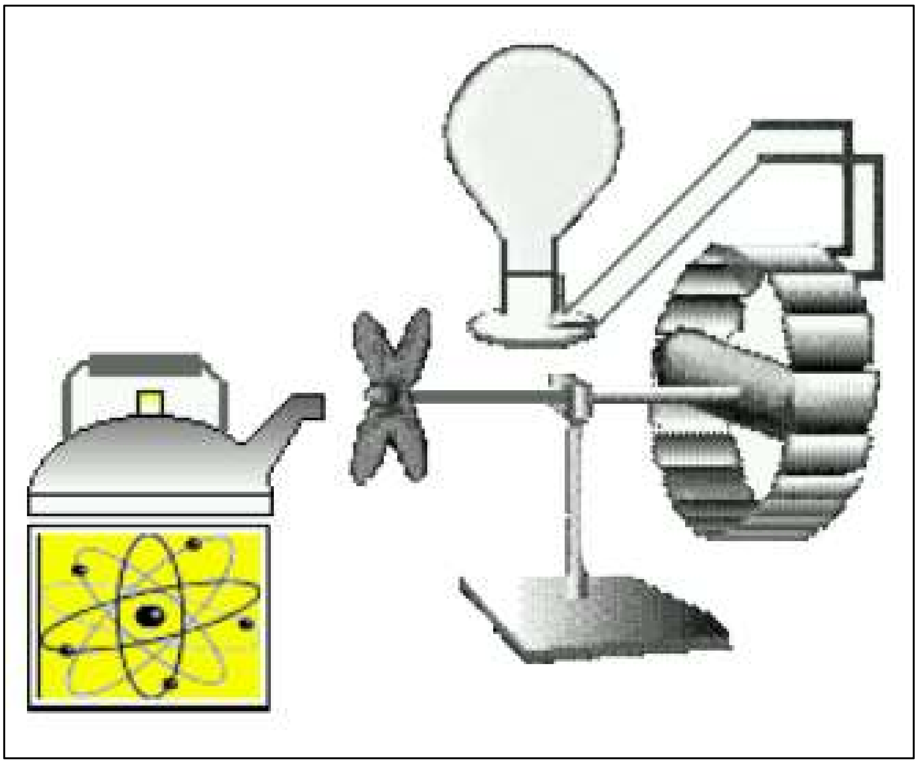


Figure 2: The Basic Tea Kettle Nuclear Powered

Remember, in a nuclear generating plant we simply change energy from one form to another. This is why so much different equipment is required.

The arrangement in figure - 2 is not very practical because the tea kettle will eventually go dry. This requires a continuous makeup of water to the kettle. Figure - 3 is a more complex view of our tea kettle and pinwheel arrangement. We are now approaching a more realistic view of how a plant cycle operates.

In figure - 3 we replace the tea kettle with a simplified nuclear reactor. The rods on top of the reactor represent the absorber rods or control rods. These rods are electronically pulled out of the core to allow the nuclear chain reaction to start. They are called absorber rods because when they are in the core, they absorb the free neutrons and stop the nuclear chain reaction. Almost all commercial nuclear reactors for power generation use absorber rods to stop or control the nuclear reaction. There are several other methods to control the nuclear reaction within a reactor, but the control rods are the primary means of control. These rods are "slammed" into the core during an emergency situation (reactor SCRAM or TRIP) to stop the nuclear chain reaction.

The nuclear chain reaction in the core creates heat. This heat produces steam. The steam from the reactor flows into the turbine. The steam impacts the blades in the turbine giving up energy. Remember, a nuclear plant is one big series of energy transfers and energy exchanges. As the steam impacts the turbine blades, energy in the form of heat is given up to the blades. This creates motion, or mechanical energy that is used to drive the generator. The steam enters the turbine at approximately 650° Fahrenheit in a nuclear plant. Once it travels through all of the blading in the turbine, the temperature in the steam has dropped to about 200° Fahrenheit.

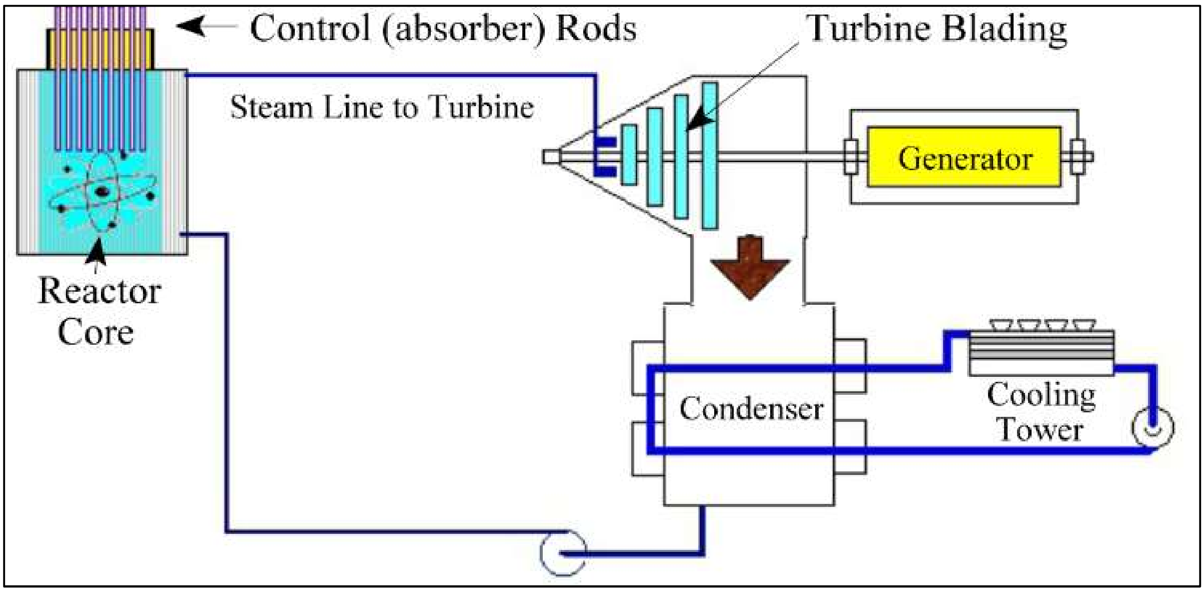


Figure 3: Simplified Plant Cycle Diagram

This creates an interesting situation that *MUST BE UNDERSTOOD BEFORE CONTINUING!* How can there be steam when the temperature is less than the boiling point of water? The answer is the same as the answer for how can you still have water when the temperature is 500° Fahrenheit? Pressure! The answer is always pressure. Water boils at 212° Fahrenheit, but only if the pressure is atmospheric at sea level. This is 14.7 psia, or pounds per square inch absolute. If you travel to the top of a 14,000-foot mountain peak in Colorado, water will start boiling at approximately 196° F. If you travel to Death Valley in California, which is below sea level, water is going to boil at slightly higher than 212° F.

The pressure that water or steam is under determines when it is vapor and when it is water. The reason we still have steam at 200° F in the last stage of the turbine is because the *condenser* has a very low pressure or what is commonly known as a vacuum in it. The next question should be,

"Where does the vacuum come from in the condenser?"

The vacuum in the condenser is primarily from the condensing of steam back to water. In the help files of "*Chernobyl, The Legacy Continues*" there is a movie that shows a gallon can being filled part way with water. The gallon can is then set on top of a Bunsen burner and brought to boiling. Once boiling, the lid is placed on the gallon can. The can is immediately removed from the Bunsen burner (or the continued heating and steam expansion would cause it to explode) and then a pitcher of cold water is poured over the top of the can. The can implodes or shrinks like air being let out of balloon. See figure - 4.

Figure 4: Contraction of Steam in Gallon Can

This is because of the massive difference in volume between steam and water. There is 1600 times more volume in steam than water in a vacuum. When the steam is cooled below its condensation point, it turns back to water, and creates a vacuum on the container. This is critical to understanding the operation of any plant. Just as heat added to water in a boiler or reactor causes the water to expand and increases the pressure, cooling the steam causes it to contract and take less space.

Figure - 5 is a copy of the "steam tables". This, or a similar booklet, will be in all nuclear and fossil fired power plant control rooms. This booklet and other similar publications lists the properties of saturated and superheated steam. An operator can look at pressure and temperature indicators in systems containing water and tell whether the system has steam in it or if it is still water. A good example is the condenser. If the operator knows there is only 2.5 psia (pounds per square inch absolute) the steam tables tell what the temperature is in the condenser.

Figure 5: Steam Tables

After the steam flows through the turbine giving up much of its energy, it flows into the condenser. In figure - 3, the condenser is the device below the turbine. The exhaust steam from the turbine enters into the top and flows downward across hundreds of small tubes. The small tubes contain cooling water from the cooling tower, pond, lake, or ocean. However, most plants use cooling towers.

The waste heat in the turbine exhaust is "transferred" to the cooling water running through the condenser tubes. As the heat is removed from the exhaust steam of the turbine, it contracts. This causes a huge volume reduction. When this volume reduction occurs, a vacuum is formed in the condenser.

This substantially increases the efficiency of the plant. It is important to note that the thermal efficiency of a modern plant is actually very poor.

If we measure the total heat in the reactor core, take that heat to generate the steam, use the steam to turn the turbine, use the mechanical motion of the turbine to turn the generator, and then make heat from the generator as efficiently as possible, we will only have approximately 1/3 the amount of heat that is in the core of the reactor. This is about 33% efficiency. It is easier to comprehend the loss of energy in coal fired plants.

We can accurately measure how much heat is available in one (1) pound of coal in a laboratory. We can then burn the same coal in an efficient boiler making steam. This steam converts to mechanical motion in the turbine, turning the generator and producing electricity. After making electricity in the most efficient manner, we will only have about 30% to 35% of the energy that was in the coal to begin with. Where does the heat go?

In a coal fired plant the majority of the heat is lost in two (2) places:

a. The exhaust gasses from the burning of the coal.
b. The condenser and cooling tower.

In a nuclear plant the majority of the heat is lost through the condenser and cooling tower. Even though there is not stack losses from combustion in a nuclear plant, the base efficiency of a nuclear plant is much less than a fossil plant. This is because a nuclear plant operates at much lower temperatures and pressures. In the *Rankine cycle*, operating at reduced temperatures and pressures dramatically reduces the efficiency of the process. Nuclear plants operate at less temperature and pressure because of safety considerations.

The basic plant cycle used in both nuclear and fossil plants is called the Rankine cycle. The Rankine cycle is the continuous cycle shown in figure - 3. This is:

a. Heating and energy storage (such as in a reactor or boiler).
b. Expansion and energy release (in the turbine).
c. Condensation and contraction (in the condenser).

When temperatures and pressures are reduced, the cycle efficiency proportionally drops.

After the steam is condensed, it drops into the bottom of the condenser. This is called the hotwell. The hotwell has pumps that return the condensate back to the overall cycle. In figure - 3, you see the flow is from the hotwell pumps back to the reactor. In reality, there are some additional pieces of equipment and other items in the cycle before it returns to the reactor. Let's add some of this equipment to make the cycle in figure - 3 more realistic.

Figure - 6 has some items added that help build a more realistic view of our plant cycle. One of the items we have added is a steam drum on the reactor. The steam drum is a collection and separation point for steam and water. Another item we have added in figure - 6 is a condensate polishing, or in-line condensate water treatment system. This is a critical item in the overall cycle of a nuclear plant. We have also added a "deaerator". A deaerator is a device that helps heat the water being fed to the reactor. It is also used to remove dissolved oxygen from the feedwater. Dissolved oxygen is very detrimental to the metal in the reactor and connected piping. If the dissolved oxygen is not removed it will cause corrosion in the systems. Besides damaging the metal in the systems, the corrosion becomes one more radioactive waste product that must be dealt with. Let's follow the new flow path in figure – 6.

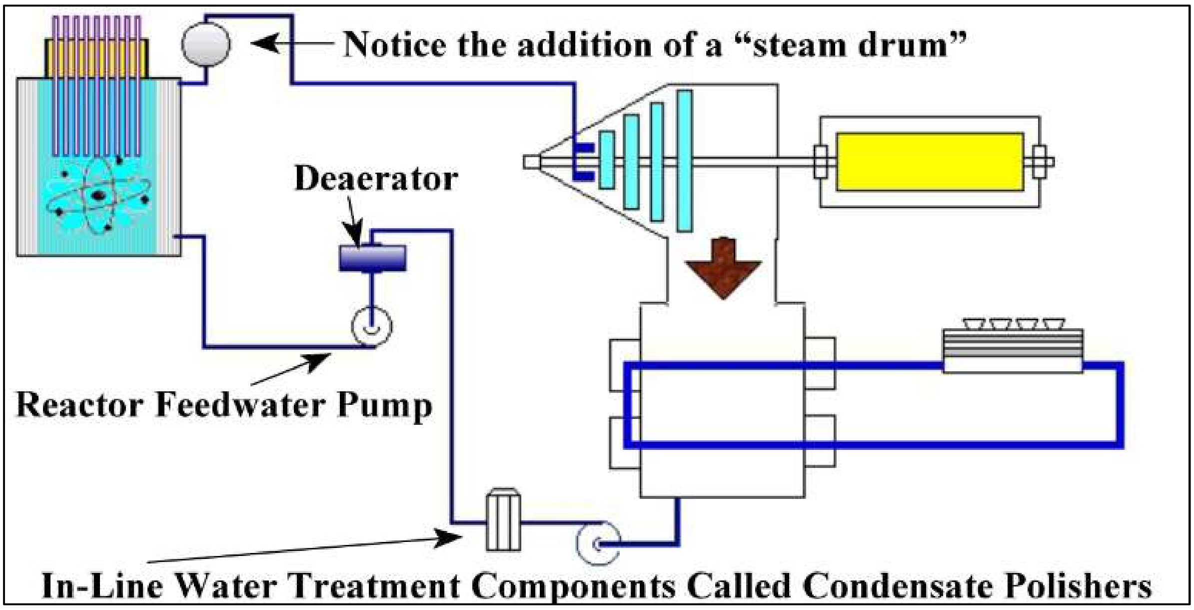


Figure 6: Flow Diagram With Simple Feedwater System

In figure - 6 we start at the reactor as we did before. We put a steam drum in here to act as a separation point between water and steam. If we simply forced the water through the reactor, we could severely damage the turbine from what is known as “water induction”. A steam turbine 1s designed for steam, not water. Water can severely damage a steam turbine. Therefore, we place a large drum that is connected to the reactor water circuit to serve as a collection point. By maintaining a level in the drum, we always know there is sufficient water in the reactor. In any plant that uses a drum such as the RBMK - 1000 reactor, drum level is one of the single most critical concerns of an operator!

Loss of level in the steam drum means the core of nuclear fuel could be exposed without cooling water around it. This exposure can lead to a meltdown or explosion of the core material. The core is not designed to be cooled by steam. It is designed to be cooled by water only. It is difficult to over emphasize the extreme importance of keeping the drum level above minimum. This need for sufficient water level is the reason so many extra systems and equipment are used in a nuclear plant to ensure that water flow is never lost to the reactor. We will cover the emergency core cooling systems later. However, you must remember the importance of maintaining the water level in the reactor.

From the steam drum, the steam flows to the turbine. After transferring much of its energy to the turbine, the exhaust steam is condensed by the cooling water in the condenser tubes and drops into the hotwell. As discussed before, the hotwell pumps force the feedwater back into the cycle. We have added a device called a condensate polisher to the cycle. Condensate polishers are water treatment devices to remove the contaminants from the water that is being pumped through the cycle to the reactor.

Pure water does NOT conduct electricity. Water is a perfect insulator if it is 100% pure water. Unfortunately, water picks up a bit of anything it touches. It is called the universal solvent. The reason that you can be electrocuted if an electrical device falls into your bath water is the contaminants in the water. Water naturally contains many minerals, iron, and other impurities. If you remove those impurities through one of several treatment methods, the water will not conduct electricity. One of the major methods used to measure the impurities in water is conductivity. Conductivity is the measurement of how much electricity the water conducts. In a large nuclear or fossil plant the water purity is extremely high. When tested, the water in the plant steam/water cycle will conduct very little electricity because of its high purity.

From the polishing system the water now flows through the *deaerator*. The deaerator is a dual-purpose device. It helps heat the water that is flowing to the reactor and it removes some of the dissolved oxygen in the water. Dissolved oxygen is a major problem in fossil and nuclear plants. At higher levels it can cause severe corrosion in the piping systems and the reactor vessel itself. The deaerator uses steam (we will cover where it is supplied from, later) to drive the dissolved oxygen off of the incoming feedwater. The deaerator is vented so that the dissolved oxygen can be removed from the feedwater. Since the feedwater is slightly radioactive on an RBMK-1000 reactor plant, the steam that is vented from the deaerator must go to treatment facilities to have the radioactive contamination removed before being vented.

Have you noticed that the Chernobyl plant, like many nuclear plants, uses a chimney or stack? This is because there are several different systems and equipment that must vent small amounts of steam and other gasses. Since most of this vented material is radioactive, it must be treated and/or filtered. The stack in these plants is the common venting point for all of the systems after being filtered and/or treated.

From the deaerator the, now treated, feedwater is pumped to the reactor by the reactor feed pumps. In figure 6, we show only one pump. You must remember how critical it is that you maintain the water level in the steam drum. This requires additional backup systems and pumps not shown here to maintain the level in the reactor. This covers the major changes in our flow diagram or schematic from figure 3.

This really isn't very complex, is it? Let's move on and add some more detail. Please refer to figure - 7 as we cover the deaerator makeup regulator control valve and the reactor makeup regulator control valve.

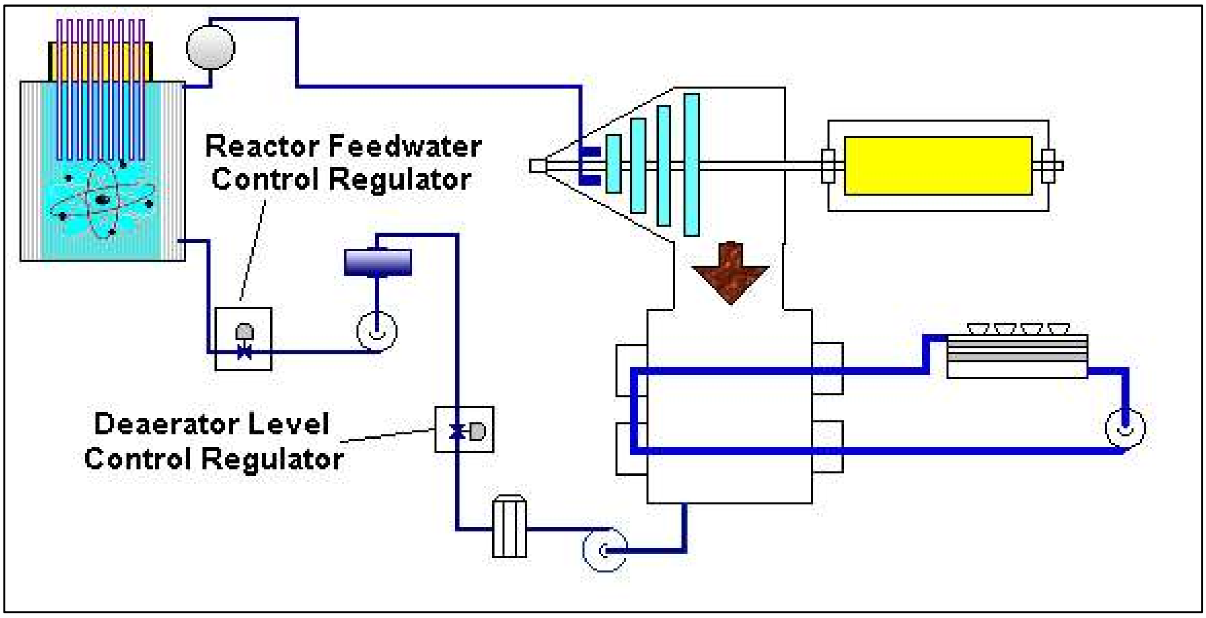


Figure 7: The Addition of Flow Control Valves to our Schematic

Figure - 7 is identical to figure - 6 except that we added two very important control valves. They are the deaerator makeup regulator control valve and the reactor makeup regulator control valve. We have emphasized the importance of maintaining proper water level in the reactor. It is important to note that if water level is lost in the deaerator, the reactor feed pumps will not have any water to pump to the reactor. Therefore, it is extremely important that the deaerator level be maintained also. Please remember, there is an emergency core coolant system (ECCS) that will flood the core in the event the normal reactor feed system is unable to maintain level. We will cover this system later.

Both the deaerator and reactor makeup regulator control valves can be operated in a manual mode by the operator. Normally both of these valves are in an automatic mode of operation by the plant control system and will maintain the levels without operator intervention. However, in low power output and upset conditions it may become necessary for the operator to place one or both of these regulators in manual and take control of the valve positions. Let's move on and look at some more cycle additions in figure - 8.

Figure - 8 is identical to the previous schematics except for the addition of a very important system that completes the overall steam/water cycle. We have added the *reactor core circulating system*, better known as the *RCCS*.

The reactor circulating pumps maintain a steady flow of water through the core of the reactor. It is important to understand that there are several types of reactors in use in the world today for power generation. The RBMK - 1000 is considered a boiling water reactor. This means that the water circulating through the core forms steam bubbles. These steam bubbles "liberate" or flow upward into the drum and out to the turbine. The water that has already been heated, but is not yet hot enough to form steam bubbles, mixes with incoming, cooler, feedwater and is forced back through the core of the reactor by the reactor circulating pumps. We have covered a very simple overview of the entire steam water cycle. Let's do a quick recap of the main points while looking at figure - 8:

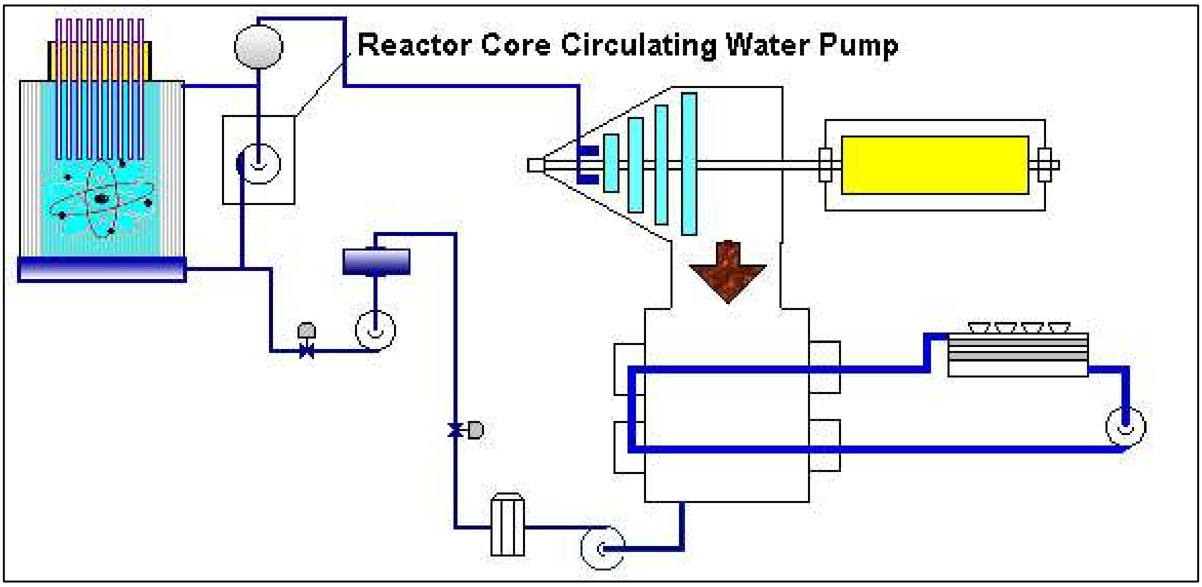


Figure 8: The Reactor Core Cooling System

1. Steam is formed in the reactor from the heat produced by nuclear fission.

2. The steam is separated from the water in the steam drum.

3. The steam flows to the turbine via the main steam line.

4. The steam gives up much of its energy in the turbine.

5. The exhaust steam from the turbine flows into the condenser tubes, condensing the steam back to water and producing a vacuum in the condenser.

6. Cooling water from the cooling tower circulates through the condenser.

> It is absolutely essential that boiling in the core be closely controlled. The RBMK has a nasty positive void coefficient that makes it produce more heat when the water content in the reactor is reduced. This means that not only low water level can cause an increase in reactivity but too much steam in the core can cause an increase in reactivity. Too much steam in the core uncovers the fuel bundles and subjects them to intense heat. The operator must never allow the power level of the reactor to increase the voiding in the core. There is a continuous readout of the amount of voiding in the reactor core. This must be watched to ensure that the core is kept in a water environment. UNDER NO CIRCUMSTANCES CAN THE REACTOR BE OPERATED WITH NO CIRCULATING WATER PUMPS OPERATING! Even during a shutdown, the core produces decay heat. This heat must be dissipated or else an increase in reactivity will occur with a subsequent meltdown and/or explosion. Let the operator beware!

7. The condensed steam is called condensate and falls into the hotwell.

8. The hotwell pumps pump the water through water treatment equipment and up to the deaerator where heat is added for preheating and driving the dissolved oxygen from the feedwater.

9. The feedwater in the deaerator flows into the reactor feed pumps where the pressure is boosted to overcome the reactor pressure. The reactor feed pump discharge is the highest pressure in the steam/water cycle.

10. The feedwater enters the reactor and is circulated by the reactor circulating water pumps. The water that is heated enough to form steam flows from the steam drum to the turbine. The cycle starts again.

This covers the main steam/water cycle of the plant. There are many subsystems that are part of the main steam/water cycle of the plant and support the operation of the plant. One of these subsystems is the extraction steam system. Please refer to figure - 9 as we cover the new additions to our overview schematic.

Earlier we mentioned that the deaerator received steam from another system. This steam was used to heat the incoming feedwater and to drive off the dissolved oxygen in the feedwater. The steam to the deaerator comes from the main turbine extraction steam system. The extraction steam system supplies numerous different parts of the plant with steam for various different purposes. The main purpose of the extraction steam system is to supply the feedwater heaters with heating steam.

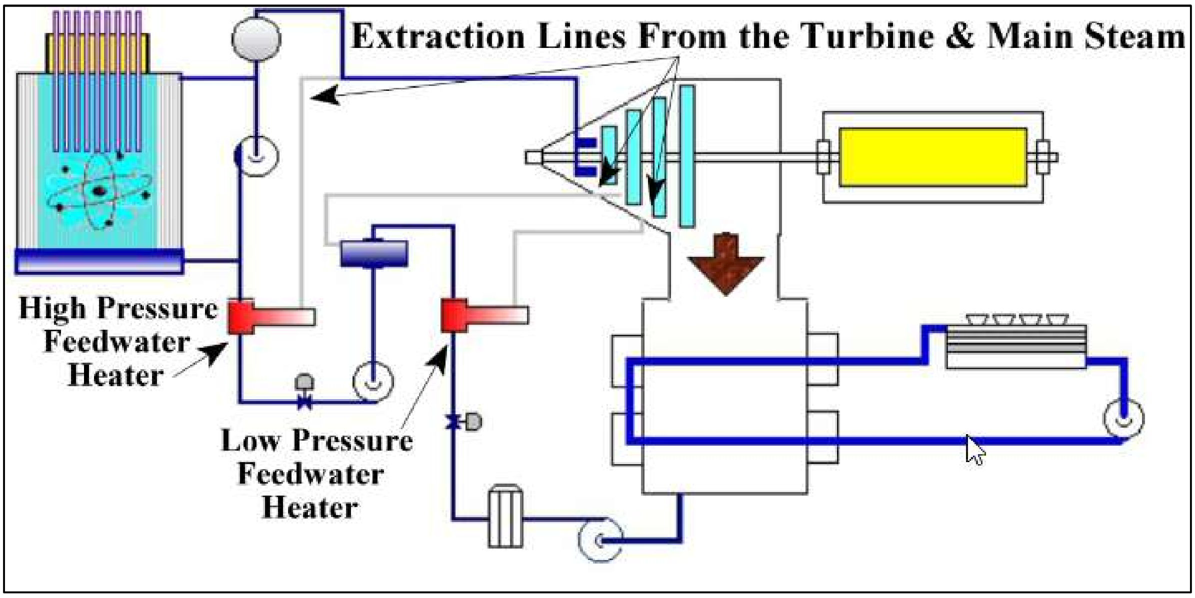


Figure 9: Plant Cycle with Extraction Steam System

Figure 9 contains two feedwater heaters and the deaerator. They are the low-pressure feedwater heater and the high-pressure feedwater heater. We are displaying only two feedwater heaters because it simplifies the schematic. In reality, plants can use several different stages of feedwater heating. A typical plant can have several low and high-pressure feedwater heaters. The purpose of feedwater heaters is to use lower pressure and temperature steam from the turbine to heat the feedwater flowing to the reactor.

Heating the feedwater supply to the reactor reduces thermal stress and shock to the reactor system. It also uses lower pressure and temperature steam from different stages of the turbine that would normally go to the condenser as waste heat. Overall, feedwater heaters increase the efficiency of the plant cycle and reduce stress to the reactor. The highest pressure extraction is from the main steam line in our diagram. However, most extractions are taken from the lower pressure stages of the turbine. This allows the turbine to use the highest pressure and temperature steam for power production before dumping it to another system that does not need the higher pressure and temperature contained in the main steam.

With the addition of the extraction steam system, we have covered the overview of the thermal plant cycle. If you feel comfortable with the material covered so far, you should not have any trouble grasping the operation of the plant. The steam/water cycle is a major part of plant operations. We will cover the actual Chernobyl plant cycle in section 6.0, *System by System Description of the Chernobyl Plant*. Section 6.0 covers the emergency core cooling system and other systems we just briefly mentioned in this section.

5.0

How Do I Properly Start a Large Piece of Equipment?

Any power plant, including a nuclear power plant, requires large pieces of rotating equipment for operation. This equipment is normally very expensive and usually temperamental. In a nuclear plant there is an added problem of contamination from radionuclides that makes even routine maintenance much more difficult. Therefore, it is very important that the equipment be placed in service properly. Failure to properly start a large piece of equipment can cause extensive damage.

Pumps are a major part of any nuclear plant. They are precision pieces of equipment and are very expensive. There are many different types and sizes of pumps that we could spend many hours studying. However, we are not going to spend a great deal of time on this subject.

We are going to learn the proper method for placing these large expensive pieces of equipment in service and move on to other more important items.

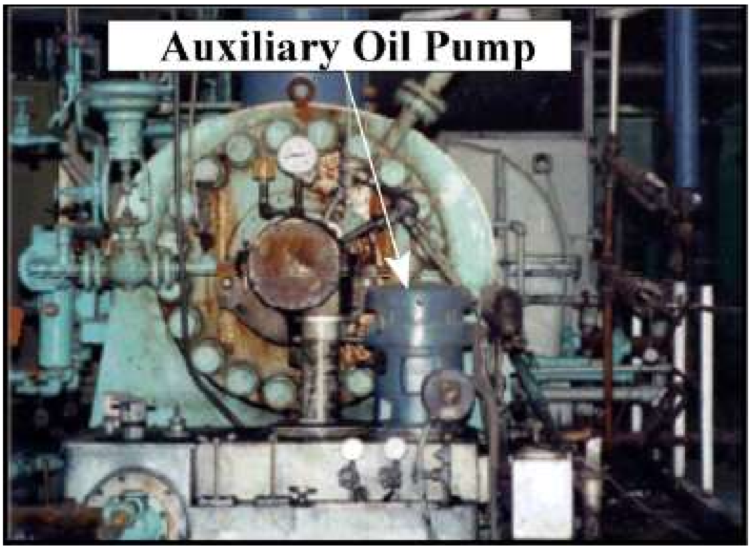


Figure 10: Reactor Feed Pump, Auxiliary Lube Oil Pumping System.

Pumps have several items that must be checked prior to and after starting. The larger the capacity of the pump the more that must be checked. Many larger pumps and pieces of equipment have auxiliary oil pumping systems that must be operating prior to starting the main pump or equipment. The oil pumping systems usually have oil reservoirs that must have the oil level checked prior to starting. See figure - 10.

If the pump does not have an auxiliary oil pumping system, it will almost always have bearing oil reservoirs with some type of oil level sight glass. These must be checked for adequate level prior to starting the pump. However, the biggest items to be concerned with are the actual valves on the pumps themselves.

The first rule to remember is that a large pump can generate tremendous heat just doing its job. For instance, reactor circulating pumps generate enough heat when all of them are operated at once to generate steam. In fact, nuclear plants perform a test called hot functionals before they even load the nuclear fuel in the core. This
means that with just the heat generated by the reactor circulation pumps they actually produce enough steam to roll the turbine and generator and produce a small amount of electricity. Obviously, the power necessary to operate the recirculation pumps is many times greater than the power generated by the turbine generator during the test.

If you do not provide a flow path for these and other large pumps they will quickly destroy themselves from a condition called cavitation. Cavitation can be caused by several items. When cavitation occurs, the pump will sound like it is pumping gravel. It will vibrate severely and generate internal heat. This heat will quickly build-up until the internal components of the pump are destroyed. What is the conclusion here? A pump must have the discharge opened after it is running. If the discharge is left closed, most large pumps have *recirculation valves*. A recirculation valve allows some of the pump's flow to recirculate back to the suction, or back to another point in the system. It is critical that the operator ensure there is a flow path. A major part of ensuring there is a flow path is opening the discharge valve... *After the pump is running*. If there is a reason why the discharge cannot be opened, it is crucial, essential, and critical that the recirculation valve be open.

If a large capacity pump is started with the discharge valve open, extensive piping and vessel damage can occur. A system must be filled slowly. Starting a large capacity pump with the discharge valve open and the system depressurized can cause a condition known as water hammer. Water hammer is very serious and can rupture pipes, valves, or pressure vessels. Beware of water hammer.

We have covered the discharge valve but there is another valve that is of equal importance. The SUCTION valve or PUMP INLET valve absolutely MUST be opened prior to starting the pump. Another valve that can be critical to some pumps is the vent valve. There are a couple of different types of vents used on pumps.

Many pumps have a casing vent valve. This valve is opened during the initial filling of the pump to ensure the casing has no air in it. After a pump is filled and the system is lined-up for operation this valve will not require opening again unless the pump or system is drained. Condensate pumps (also called hotwell pumps) must be operated with the vent valve open all of the time. The vent valve covered earlier in this paragraph is open to atmosphere. The vent valve on the condensate pump is connected, via a pipe, to the condenser.

Do you still remember that the condenser is under a vacuum? A pump cannot physically pump from a vacuum. Therefore, for the condensate pump to remove the water from the hotwell, it must be at the same pressure as the condenser. This is why the vent valve must be open to the condenser. Failure to open the condensate pump vent will result in the condensate pump failing to pump the water from the hotwell.

There is one other area that must be covered in the starting and operation of a large pump. If the suction valve is open. but there is NO water to pump, the same effect occurs as if the suction valve is closed. A pump must have adequate *Net Positive Suction Head* (NPSH) requirements. This simply means that the pressure to the pump suction must be above the manufacturers minimum or else the pump will be damaged. Every pump is different. As a general rule, the larger the pump the more suction head that is required for operation. Just be sure to keep adequate hotwell level, deaerator level, and reactor drum level. If the levels are okay, the pumps will probably have adequate suction pressure.

Let’s do a quick review of what is required to start a large pump:

1. Suction valve open.

2. Lube oil system operating (if equipped).

3. Bearing lube oil level(s) adequate if no auxiliary oil pumping system is used.

4. Adequate level in the vessel to be pumped from.

5. Vent valve open if it is one of the condensate (hotwell) pumps.

6. Recirculation valve open (if equipped).

7. Discharge valve opened (after the pump is started and up to speed).

This covers the major details of starting a large pump. This is just the tip of the iceberg but you now know enough to operate the plant. Just remember the items covered here and you will do fine.

6.0

System by System Description of the Chernobyl Plant

We have covered the overall steam/water cycle in a generic plant and have even covered some minor details of the RBMK-1000. We are now going to get more specific to the Chernobyl Plant. We are going to jump right into the schematic diagram used in *Chernobyl, the Legacy Continues*. A schematic diagram is a one-line pictorial view of the major flow paths and systems at the plant. Another name for this type of drawing is a *P & I D*. This stands for *Piping and Instrumentation Diagram*. The schematic or P & I D is very similar to the actual flow paths and equipment in the real Chernobyl plant. We have tried to keep the schematic and the simulation as technically accurate as possible. There are many items simplified but, by and large, we have kept the overall plant systems and equipment accurate.

If you select Help from the pull-down menu in *Chernobyl, the Legacy Continues*, and then select SYSTEM BY SYSTEM DESCRIPTION you will find a fully interactive schematic diagram that allows you to click on a piece of equipment and receive a multimedia explanation. This user's manual follows the general direction of the multimedia training in the help files of the Chernobyl program. If this document fails to explain it in an understandable manner, you should go to the multi-media help files in the Chernobyl program. You might find them easier to understand.

Figure – 11 is the key or legend used to identify the parts or

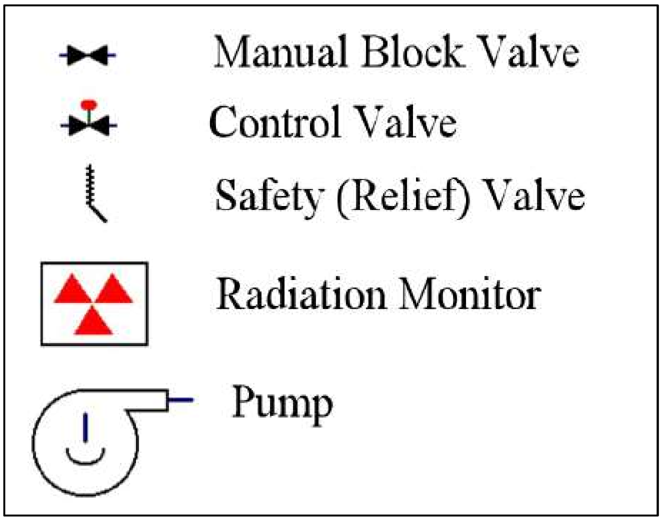


Figure 11: P & ID Legend

components on the schematic or P & ID. Refer to it as needed as you cover the actual P & ID. We have included 5 items on the legend that you must be able to identify on the P & ID. The actual schematic diagram or P & ID is located in figure 12 on the next page. We are going to start our cycle overview at item #1, the water treatment plant (WTP) pumps located in the lower left-hand comer of the schematic.

You should notice that every item on the schematic (figure - 12) is numbered. This number is the identification number for the documentation presented below. USE THEM:

1. Demineralized Water Supply Pumps: The demineralized water supply pumps are located in the lower left-hand corner of the P& I D and are controlled from the Water Treatment Pumps and Condensate Storage control. There are two (2) electrically driven pumps, each one capable of supplying all the make-up water needs to the generating unit. This includes emergency supply needs for the emergency reactor cooling (ERC) system. The maximum flow on each pump is 3,500 Gallons Per Minute. The logic for starting either pump includes suction valve open, discharge valve closed, and at least one condensate storage tank make-up valve open. If neither condensate storage tank is ready for operation, the pumps will not start. Failure to meet these *permissives* causes a "Water Treatment Makeup Pump failure" alarm to sound. A permissive is any item that is required by the control system logic to start a piece of equipment.

After the pump is at rated speed (approximately 7 seconds run-up time), the discharge valve can be opened without the pump shutting down. The demineralized water makeup pumps have the following controls:

a) Pump - 1 Start and Stop buttons with % of rated speed.
b) Pump - 2 Start and Stop buttons with % of rated speed.
c) Pump - 1 Flow valve open and close button with % open indicator.
d) Pump - 2 Flow valve open and close button with % open indicator.

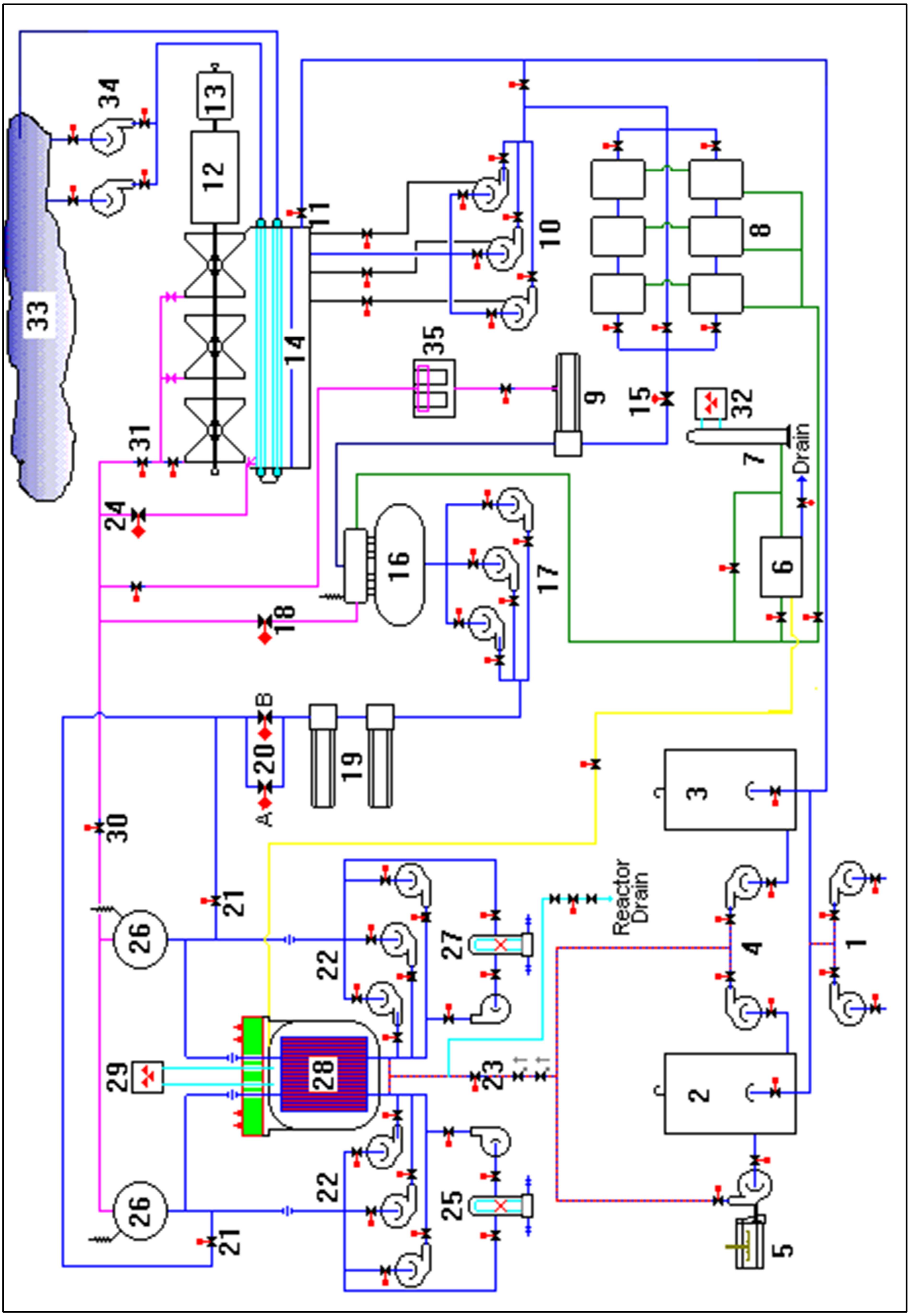


Figure 12 - Chernobyl P & ID

2, 3. Condensate Storage Tank - 1 and Tank - 2: The condensate storage tanks are vented carbon steel tanks with poly linings. These tanks have a local level indicator and digital level indicator on the Water Treatment and Condensate Storage control. The tank level is measured from 0' to 30. Each foot of water in each tank is the equivalent to 32,000 gallons of condensate. Total condensate storage for each tank 1s 960,000 gallons. Makeup water to the storage tanks cost 5 roubles per gallon due to the extensive treatment necessary. All of the water from the water treatment plant for use in the reactor has been softened and demineralized. This means that virtually all contaminants have been removed and the water will not conduct electricity. Initial condition of the tanks is always 12% in tank number - 1, and 12% in tank number - 2. If you wish to "top one off" you must start the demineralized water supply pumps. Remember, reactor water is very costly produce.

Connections to the tank include a combination inlet and outlet valve controlled from the Water Treatment Pumps and Condensate Storage control. When the WTP makeup pump(s) is/are operating it allows flow into the tank. When the WTP makeup pump(s) is/are off it allows vacuum drag of the condensate into the plant condenser. There is a second connection to the electric driven emergency reactor cooling (ERC) pumps. The third and final connection from the condensate storage tank is a line to the backup diesel driven emergency reactor cooling (ERC) pump.

4. Emergency Reactor Cooling (ERC) Pumps: The emergency reactor cooling (ERC) pumps are electrically driven, full capacity pumps. Either one is capable of supplying 8.5 million pounds per hour of water to the reactor. The controls for these pumps are on the Emergency Core Cooling System control. Due to the nature of the emergency core cooling system, it can be placed in service at any time. However, when used for any reason, the reactor will automatically scram as a safety precaution.

The controls and indicators for the pumps include pump status, suction and discharge valve status, reactor cooling circuit pressure indication, and start/stop, open/close pushbuttons for pumps and valves. An emergency reactor cooling (ERC) AUTO pushbutton is also on the control panel.

This AUTO push button automatically aligns the ERC pumps for operation and starts the pumps when needed. When removed from AUTO, an alarm will sound stating "ERC Pump - 1 (or 2) Manual Lockout". This alarm will be maintained until the pump is placed back into AUTO.

5. Diesel Driven Emergency Reactor Cooling (ERC) Pump: This pump is functionally the same as the electric driven ERC pumps in item - 4. The only difference is the diesel driver does not require an electricity source to operate. Since it is pneumatically started on a "dead-bus" (loss of station service) signal, no electricity is required. All of the controls are the same as for the electric driven ERC pumps with one notable exception. The diesel driven pump has a speed control setting that must be controlled by the operator. When started, the pump comes up to a 450 RPM idle setting. The operator should increase its speed to 900 RPM for maximum flow. Flow from the pump will quickly diminish when the engine RPM is below 800, and will be almost gone (assuming rated pressure in the reactor cooling circuit) at 750 RPM. On the converse side, the engine will have a "danger, high diesel driven ERC RPM" alarm come in at 1000 RPM. The diesel will destroy itself and require rebuilding if operated above 1050 RPM.

6. Steam Vent HEPA Filter System: The steam vent HEPA filter system is designed to remove radioactive particles from the deaerator vent system, reactor helium radiation detector vent system, and reactor containment vents. The controls for this system are on the HEPA Filter control. The controls include an IN service button, an OUT of service button, and a BYPASS button. The bypass valve has a position indicator on the control panel. The bypass valve is designed to bypass the HEPA filters as needed to maintain the "differential pressure" across the filters at an acceptable value. Differential pressure is the pressure difference between the inlet and outlet of a pressurized pipe, vessel, or piece of equipment. Example: If the pressure into the filter unit is 25 psi and the pressure out of the filter unit is 10 psi there is 15 psi differential. This is commonly written as 15 psid (per square inch *differential*).

There is also a percent of contamination indicator located on the panel. The percent of contamination indicator indicates the level or degree of radioactive contamination on the HEPA filter. There are three alarms associated with this system. They are HIGH RADIATION IN HEPA FILTER. HIGH RADIATION IN VENT STACK, and HIGH RADIATION IN CONTAINMENT. On the HEPA filter control we also have a vent flow control and a bypass control. The bypass valve must be opened to relieve pressure on the HEPA filters when contamination is too high to adequately pass necessary flow through the filters.

This will cause high radiation alarms to sound in the vent stack, based on how much the bypass around the HEPA filters opens. Continued operation will produce increased bypass valve opening which will increase the amount of radiation up the vent stack. The cost to replace the HEPA filters is very high. Therefore, they should only be changed when needed.

7. Plant Vent Stack: The plant vent stack routes the slightly radioactive gasses from the HEPA filter system to the atmosphere. The only panel indication is a radiation indicator on the HEPA Filter control. The “High Vent Stack Radiation” alarm sounds at 1 rem.

8. Condensate Polisher System: The condensate polisher system consists of two (2) 100% capacity in-line demineralization trains. The controls for the condensate polishers are in the control room on the condensate system control. The polisher control and indicators consist of polisher - 1, IN and OUT of service buttons, polisher - 2 IN and OUT of service buttons, a regenerate button for each system and a status light for each system.

When an in-line condensate demineralizer (polisher) unit “exhausts” itself, the PH (measure of acidity) decreases and the conductivity (the measure of how much current the water will conduct, which indicates the impurities in the water) increases.

When the condensate system purity begins decreasing due to an exhausted polisher, the alarms sounds at 2 micromhos or greater conductivity. The operator must place the standby vessel in service by pressing the IN button and take the exhausted unit out of service by pressing the OUT button.

When the low condensate quality alarms sound, the spare in-line demineralizer (polishing unit) must be placed in service. This is an operator completed function. It is not automatically done by the computer or the control system. If you do not go to the Condensate System control and start a regeneration of the exhausted polishing system, the in-service unit will eventually exhaust itself. When the in-service unit exhausts itself the condensate, feedwater, and reactor water chemistry will deteriorate so much that it will require a reactor unit shutdown. Operating with decreased water quality increases overall maintenance costs on the unit.

To place a polishing unit in the regeneration mode, you must press the REGENERATE button in the Condensate System control. This will automatically complete a regeneration and place the unit in standby until needed. Operation or regeneration of a polisher requires at least one hotwell pump to be in operation.

9. The Low Pressure Feedwater Heater: The low pressure feedwater heater is a tube and shell heat exchanger as shown in figure - 13. This is a simple heat exchanger. Heat exchangers are an integral part of any energy system. As the name implies, heat exchangers are used for energy transfers. They are designed to move, or exchange energy in one system to another. In the case of a feedwater heater, steam energy from a turbine extraction or the main steam system flows into the top of the heat exchanger. This is called the shell side. It is called this because the steam flows freely around a series of tubes that contain the condensate or feedwater.

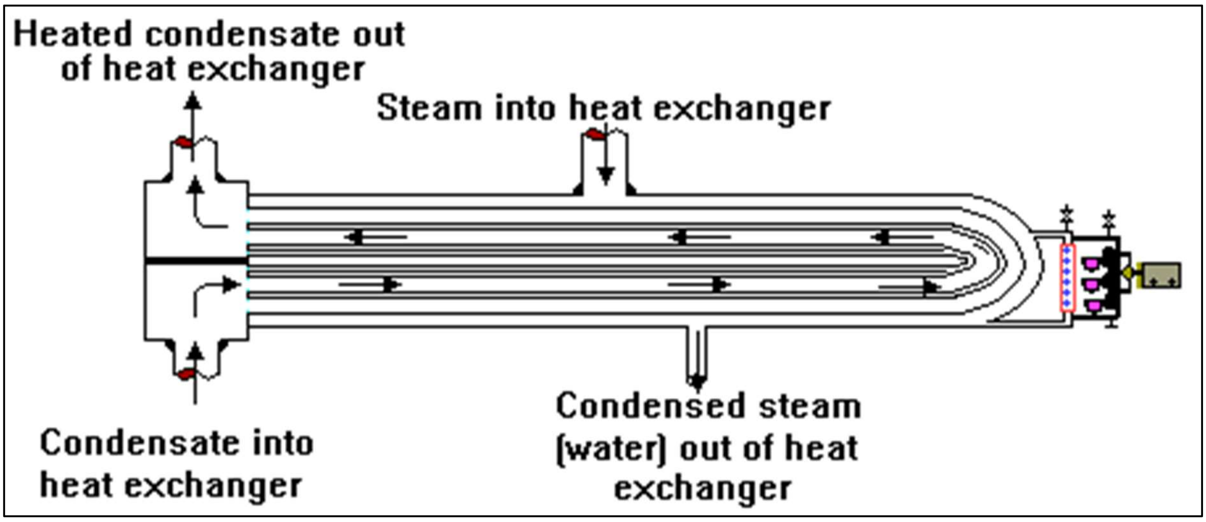


Figure 13- Typical Feedwater Heater

This portion of the heat exchanger is called the tube side. There is NO connection between the shell side and the tube side. The condensate flows in and out of the feedwater heater through the tubes that run through the tube side of the heat exchanger. The steam into the shell side of the heat exchanger flows in and around the *tubes.*

As the hot steam comes in contact with the much cooler tubes on the tube side, heat is given up from the steam (exchanged) to the condensate or feedwater on the tube side. As more heat is exchanged, the steam condenses, or turns back to water and flows out the bottom of the heat exchanger. This condensed water or condensate can flow to the plant condenser or to another heat exchanger with an even lower mean temperature. Please remember, the purpose of the condensate or feedwater heater is to increase efficiency of the system and reduce thermal shock to the reactor.

10. Condenser Hotwell Pumps: There are three (3) condenser hotwell pumps controlled from the Condensate System control. The condenser hotwell pumps are very large, vertical, can type, centrifugal pumps. Two (2) of them are required for full load operation. They are equipped with suction. discharge, and vent valves that are controlled automatically when the pump is selected to START.

There is NO low hotwell level permissive for starting the hotwell pumps, and NO hotwell level trip for the pumps. If the hotwell pumps are operated with no water (either started or run dry during operation) the pumps will simply quit pumping. If either of these conditions are not corrected within a few minutes, the pumps will be “ruined” and cost a tremendous amount of money to repair.

11. Hotwell Makeup Valve: This valve is controlled from the hotwell level control. When in AUTO, the setpoint should be 0”. This valve will hold level in AUTO if there are NO malfunctions and if either one of the condensate storage tank make-up valves are open and an adequate level exists, or if the WTP make-up pumps are operating. Since the condenser is under a vacuum, the water from the condensate storage tanks is drawn into the condenser by the vacuum. This is commonly called a vacuum drag system. It is important to remember that the hotwell level is an extremely critical item. This is because low level will stop the pumps from pumping.

This causes the entire cycle to lose water flow, scramming the reactor and starting the emergency reactor cooling systems. High level is equally serious because when the hotwell is too full, the tubes carrying the cooling water are covered by the condensate and the exhaust steam from the turbine quits condensing. This causes the condenser to lose vacuum, the turbine to trip (emergency shutdown) and the reactor to scram. To start a condensate pump you must select the condensate system control, and then click the ON button for the desired hotwell pump. The suction, discharge, and vent valves function automatically on this pump.

12. Generator: The generator is a very large (1000 megawatt) hydrogen cooled, two pole generator. It turns 3,600 RPM. There is little that an operator does with the generator except maintain cooling water flow to the heat exchangers built into the generator casing and maintain proper hydrogen pressure within the casing. The oil to the bearings is supplied by the turbine oil system. The generator voltage is controlled by the amount of excitation or D.C. voltage being supplied to it from the exciter.

It is important to remember that the amount of load, or megawatts the generator produces is entirely dependent upon how much horsepower the turbine is supplying to it. Mechanical horsepower into the generator will always equal electrical energy out of the generator. This goes back to the most basic of basics in physics... Energy in = Energy out, minus the losses in the cycle. These losses are primarily heat losses through the cooling system and friction losses through the bearings. Both of these losses are very minimal.

13. Exciter: The exciter is a small generator that supplies the direct current (D.C.) necessary to maintain the rotating magnetic field in the main generator. It is important to note that the generator output voltage is increased or decreased by increasing or decreasing the amount of D.C. voltage from the exciter to the generator field. This is an operator function based on the overall power system (grid) voltage and the whims of the power dispatcher who oversees the power system (grid) operation.

14. Hotwell and Condenser: The condenser is the large device that has cooling water from the cooling tower flowing through the tubes, condensing the turbine exhaust steam back to water. Figure – 14 is a side view of a turbine and condenser.

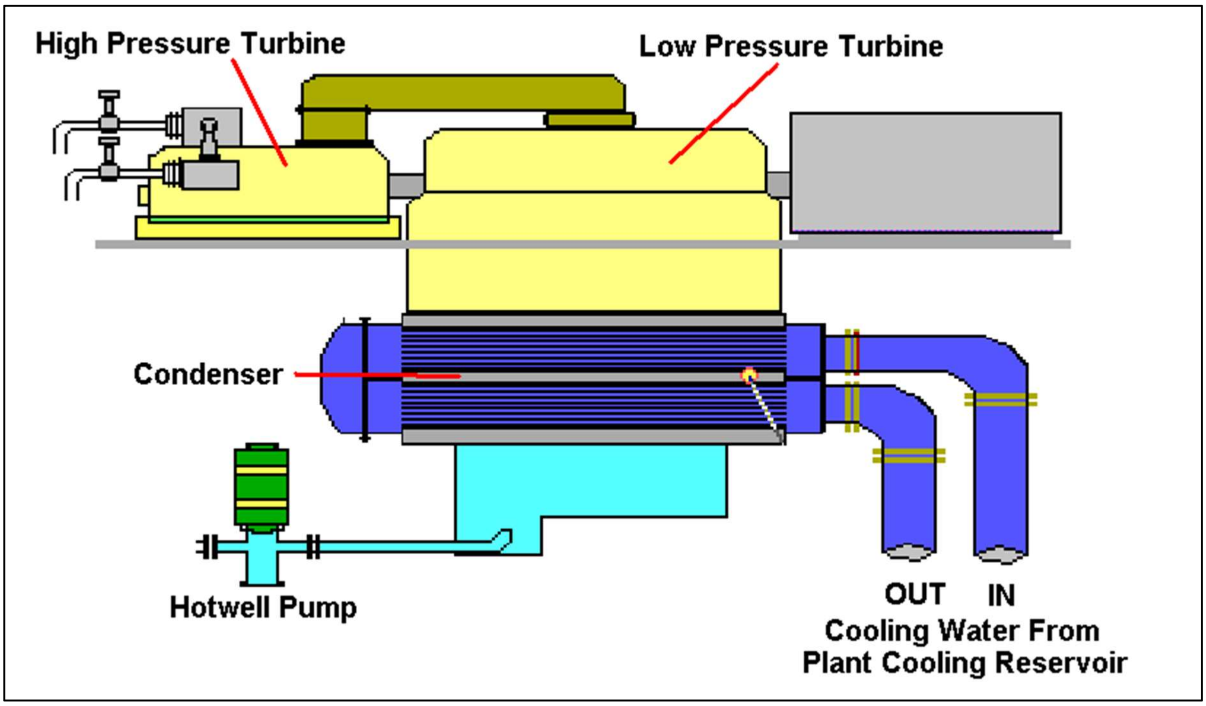


Figure 14 – Side View of Turbine and Condenser

The condenser, much like the feedwater heater we looked at earlier, is nothing more than a very large heat exchanger. In fact, it is physically the largest heat exchanger in the entire plant. The turbine exhaust flows across the tubes that have the cooling water flowing through them. As explained many times already, the cool water in the tubes removes the remaining heat in the turbine exhaust. This causes the turbine exhaust steam to turn back to water (condense). When the exhaust steam turns back to water, a vacuum is formed in the condenser.

The amount of vacuum or negative pressure in the condenser is very important to the overall operation. If the vacuum decreases too much (that is, the amount of vacuum in the condenser decreases and the condenser starts to have a positive pressure) the turbine will trip (emergency shutdown). The turbine must have a high negative pressure in the exhaust or damage to the turbine blades can occur due to steam condensing to water on the turbine blades. Why would water condense on the turbine blades? Pressure! Remember when we earlier said that the answer is always pressure.

As the condenser pressure increases, the temperature at which steam turns to water increases. Since most of the energy has been removed from the steam, it can actually start to condense in the turbine blades.

Remember, the turbine is spinning at 3,600 RPM (in the United States the turbine generators spin at 3,600 RPM on two pole generators). If these long blades contact water droplets, serious damage and even breakage can occur due to thermal differential and impact.

All power plant condensers have some form of vacuum equipment to help maintain vacuum in the condenser. This is because air and other non-condensable gasses get in the steam/water cycle. These gasses, if not removed by vacuum equipment, will build-up in the condenser causing it to lose its vacuum. Again, this will trip (emergency shutdown) the turbine. Vacuum equipment can be mechanical, electric driven vacuum pumps or the vacuum equipment can be in the form steam venturis. A steam venturi, or steam jet air ejector uses steam in a venturi arrangement to remove air and other non-condensable gasses and create a vacuum. This will be covered in more detail under item - 35, the steam jet air ejectors.

The hotwell is the catch basin on the bottom of the condenser where the condensed steam (condensate) is stored. The hotwell stores a large amount of condensate. The level in the hotwell is controlled by a level control valve that opens when the level drops below setpoint to pull water into the condenser.

A major problem in any power plant is a leak in any one of the thousands of condenser tubes. Since the condenser is filled with small diameter tubes that have cooling water from the cooling tower flowing through them, a leak causes the very impure cooling water to be drawn into the hotwell. Remember, there is a vacuum in the condenser. When a cooling water tube leaks, the ultra-low pressure in the condenser sucks the water from the leaky tube into the hotwell.

A condenser tube leak is very serious because the water in the hotwell is extremely pure. The cooling water on the other hand, is very dirty. It flows through the cooling tower and has air drawn through it to cause evaporation. Evaporation increases the contaminants in the cooling water due to a concentrating effect. Only the water evaporates, the impurities stay behind in the remaining water. In addition to the concentrating effect, the cooling water is bombarded with dust and dirt in the cooling towers themselves.

When this foul cooling water enters the hotwell because of a condenser tube leak, it rapidly decreases the purity of the condensate. This causes the condensate in-line polishing system to exhaust very quickly. The worse the leak the faster the polisher will exhaust as it attempts to maintain the high purity of the condensate. This causes the polishers to exhaust quicker than they can be regenerated. When this happens, the overall steam/water cycle purity dies, and the plant has to be removed from service. Let the operator beware! The Chernobyl plant has a lot of condenser tube leaks!

15. Deaerator (DA) Level Control Valve: The DA level control valve is controlled from the Condensate System control in the main control room. In AUTO it will maintain the level at 0". When in manual, the operator can adjust the flow by opening and closing the make-up valve from its controller. If there is no condensate flow to the DA when the plant is at full power output, the level in the DA will decrease to the point where the reactor feed pumps will quit pumping in about three (3) minutes.

There will be many warning alarms that the flow and, eventually, the level is low. It is important to remember that loss of DA level means the reactor feed pumps will quit pumping. If this happens, the emergency reactor feed system will be required to supply the essential water to the reactor. Any time the emergency reactor cooling system is started, the reactor is scrammed for safety purposes. Therefore, loss of DA level is serious for a number of reasons:

a. The incredibly expensive reactor feed pumps will be ruined. These are the most expensive pumps to replace in the plant.

b. The reactor will scram, shutting down the entire plant.

c. The Emergency Reactor Cooling (ERC) system shocks the hot reactor with cold water.

d. The time frame for a restart after a scram and ERC action is at least two days. This equates to a tremendous amount of roubles lost due to down time.

16. Deaerator (DA): The DA is considered an open feedwater heater. Unlike the feedwater heater heat exchanger we covered in item - 9, the steam and condensate are in complete contact with each other. See figure - 15. The DA has two purposes. The first is to drive-off the dissolved oxygen and other non-condensable gasses from the condensate. The second purpose of the DA is to help heat the incoming feedwater.

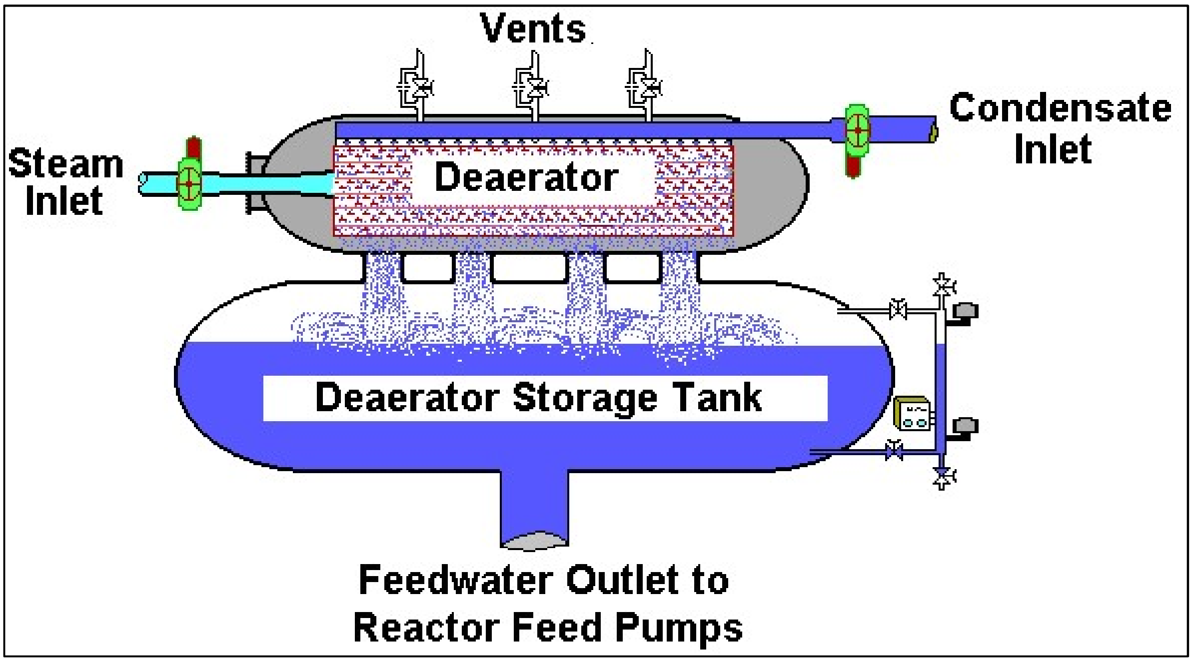


Figure 15: Deaerator (DA) Open Feedwater Heater

The DA is filled with trays that the incoming condensate flows over and across. This breaks the condensate into fine droplets. The steam into the deaerator blows over the trays and causes flash evaporation of the condensate. The condensate then re-condenses as it falls through the trays to the storage tank. This action liberates or frees the dissolved oxygen and other non-condensable gasses. These gasses rise to the top of the deaerator and exit from the vents.

When we speak of the level in the deaerator, we are actually talking about the level in the DA storage tank beneath the DA. The DA itself has no level in it. The condensate falls through the trays into the storage tank. This is where the actual level is maintained. Normal level in the DA (storage tank) is 0".

The steam to the DA is regulated by a pressure control valve (Item 18 on the schematic). The normal pressure in the DA is between 16 and 25 psig. Excessive steam pressure initiates an alarm. You must open the deaerator vent at least 50% to maintain water chemistry.

There are six (6) alarms for abnormal water level in the DA:

a. Deaerator Flooded - Emergency High Level. This is a serious problem because flooding the DA will flood the HEPA filters requiring replacement. Allowing the DA to flood is very expensive because you must replace the HEPA filter system. This alarm comes in when the DA level is above + 15".

b. Deaerator High High Level. This closes the main steam line feed valve to prevent the DA high level from backing water into the steam system. When the steam valve from the main steam line to the DA closes, water chemistry starts deteriorating. This alarm comes in when the DA level is above + 10".

c. Deaerator High Level. This is self-explanatory and the first step towards warning the user of a problem. This alarm comes in when the DA level is above + 8".

d. Deaerator Low Level. This is self-explanatory and the first step toward warning the operator of a problem. This alarm comes in when the DA level drops below - 8".

e. Deaerator Low Low Level. This is the prelude to the reactor feed pumps being ruined and the Emergency Reactor Cooling System starting and, of course, the reactor scramming.

f. Deaerator Low Level - Reactor SCRAM. This alarm announces that the reactor has went into an emergency shutdown, and the Emergency Reactor Cooling (ERC) System has started. If you do not shut down the reactor feed pumps in less than two (2) minutes, they will be ruined at tremendous cost.

17. Main Reactor Feed Pumps: The three (3) main, electric driven, reactor feed pumps are 70% capacity each. This provides for 140% capacity flow on two (2) pumps with one spare pump at all times. The starting permissives for a reactor feed pump requires the suction valve

to be open, and the discharge valve closed if the pressure in the discharge header is less than 500 psig. The DA level must be above low alarm level also. As stated previously, an empty DA level will scram the reactor, start the ERC system and ruin the reactor feed pumps if they are operated for more than two (2) minutes without water. The reactor feed pumps are controlled from the feedwater and system control.

18. Steam Supply to the Deaerator: This valve is controlled from the deaerator steam supply control in the main control room. Normal pressure setpoint when in AUTO is 16 to 25 psig, with the DA vent at least 50% open.

19. High Pressure Feedwater Heaters: The purpose of the high-pressure feedwater heaters is to decrease the thermal shock to the reactor by increasing the feedwater temperature. The steam to the high-pressure feedwater heaters is supplied from a high-pressure extraction from the main turbine. The high-pressure feedwater heaters work exactly as the low-pressure feedwater heater in item - 9. Please refer to item - 9 and figure - 13.

20. Reactor Feedwater Regulator: The reactor feedwater regulators consist of two (2) multi-range regulators. The feedwater flow into the reactor is so high that just using one (1) valve would require that the valve be too large and cost too much. Therefore, there is a low range regulator and a high range regulator. They are both controlled from the Feedwater Pumps and System control. If these valves fail, the consequences are quite serious.

If the reactor feed valve(s) fail open, the reactor steam drum will flood and cause the turbine to trip to prevent water induction. If the reactor feed valve(s) fail closed the reactor water level will fall to dangerous levels and require the reactor to SCRAM and the emergency reactor cooling (ERC) system to flood the reactor with cold water. Either of these situations are, of course, serious and should be avoided. Item – 21 on the schematic, the reactor feed isolation valve(s) are a backup to the reactor feed valves in the event they fail open. See item - 21, below. The reactor feed control valves are controlled from the feedwater pumps and system control. The high and low range valves are labelled STARTUP VALVE and MAIN VALVE on the feedwater pumps and system control. The startup valve is usable until about 20% of rated power. The main valve must be put in service over 20% power output or loss of reactor level will occur.

Also on the Feedwater Pumps and System control is a selection for THREE ELEMENT CONTROL. THREE ELEMENT CONTROL is designed for use only when using the MAIN feedwater regulator. THREE ELEMENT CONTROL is a control system that *looks* at steam flow to the turbine and balances it with feedwater flow. The reactor drum level is the third element and functions as a trim to steam flow and feedwater flow. When not in three element control, the only item that the control system *looks* at it is the drum level. This is okay for low power output. However, when plant power levels are raised enough to require the main feedwater valve, three element control should be selected for smoother, more accurate reactor level control.

21. Reactor Feed Isolation Valves: There are two (2) identical valves, one for the left steam separator drum and one for the right steam separator drum. These valves are designed as isolation valves that are either fully opened or fully closed. It is recommended they remain open at all times.

22. Reactor Circulation Pumps: There are three (3) identical pumps for each of the two (2) reactor circuits. Each circuit requires two (2) pumps for normal operation. This, of course, leaves one pump as a backup on each circuit. The start permissives for these pumps are the same as all the rest. The suction has to be open, and the discharge must be closed. Once a pump is started, the discharge valve must be opened by the operator. These pumps are very large and very expensive to replace or repair.

These pumps are controlled from the Loop - 1 and Loop - 2 Recirc Pumps control. These pumps work in combination with the absorber rods to control the amount of voiding in the reactor. Remember, the RBMK -1000 has a positive void coefficient. This means that the power level increases as the fuel temperature increases. You can bias the flow from the reactor feed pumps on the recirc pumps control.

23. Emergency Reactor Cooling (ERC) Control Regulator: This is the regulator that controls how much water is dumped to the reactor when a loss of coolant from the primary system occurs. This valve is triggered open by any loss of core coolant excursion, and any high temperature condition in the core. Anytime this valve is opened more than 5%, the reactor will automatically SCRAM if it has not done so already.

The automatic SCRAM when the valve opens should reinforce the importance of not operating this valve except in an emergency. This valve, when wide open with one or more of the ERC pumps running, will flood the drum steam separators (when off-line) in about two (2) or three (3) minutes. If this system is allowed to run unrestrained, the separator safety valves and the main steam safety valves will “blow” when the entire reactor water system fills to capacity. This will ruin the safety valves because they are designed for steam, not water. This is very expensive to repair. **The operator must pay close attention when using the emergency reactor cooling (ERC) system.** There is no operator controllable level when on the ERC system. The operator simply floods the reactor and then stops the flow. Cooling is achieved by bleeding steam from the flooded reactor to the condenser. After flooding the reactor with the emergency reactor cooling system, the operator should place the shutdown core coolant system into service if available.

24. Main Steam Dump Regulator: This valve is controlled from the Main Steam Dump control. The valve is designed to pass 30% of maximum rated steam flow at rated reactor pressure. It is used during transients, start-up, and shut-down of the reactor to stabilize steam flow, pressure, and temperature to prevent major upsets to the turbine during these time periods. This valve is equipped with AUTO and MANUAL settings. In AUTO the operator must provide a pressure setpoint. In manual, the operator controls the amount the valve is opened. The main steam dump control indicates steam flow and valve opening as well as allows the operator to place a pressure setpoint that the system controls at.

25 & 27. Reactor Off-Line Core Cooling System: There are two heat exchangers (see item - 9 for an explanation of what a heat exchanger is), and two coolant pumps. There is one (1) heat exchanger and one (1) coolant pump for each loop. This system uses plant cooling water to cool the decay heat from the reactor when it is shutdown. **Shutdown cooling systems in commercial power reactors are critical.** The longer a reactor operates on a load of fuel, the more radioactive decay products build-up. The build-up of decay products produce heat even when the control (absorber) rods are fully in and the reactor is SCRAMMED. This decay heat can be as much as 7% of the full power output of the reactor.

This is one of the larger operating problems faced by a nuclear plant. They can't fully shutdown a reactor for several days due to the decay heat problem. This is why so many backup systems are used to maintain water flow to a nuclear reactor.

If there was not a problem with decay heat a reactor would be far safer to operate. This is because when a problem developed the reactor could simply be shutdown and the problem repaired. However, nuclear reactors still produce several million BTU (British Thermal Units) of heat after they are shutdown. The Chernobyl reactor is rated at 3000 megawatts thermal. If there is 5% decay heat being generated after it is shutdown, this means that 150 million watts of energy must still be handled after, yes after the reactor is scrammed.

If the plant is not capable of maintaining cooling flow for whatever reason, the core of the reactor will boil dry. When it is boiled dry the temperature of the core will skyrocket. Please remember that the positive void coefficient of the RBMK makes the power production radically increase as the water is boiled away from the core material. This means that if you can't continue to cool the core for several days after the SCRAM, a serious or even catastrophic accident will occur.

The shutdown core cooling system consists of a heat exchanger on each loop and a pump for each loop. The controls for the pumps and the heat exchangers are located on the Off-line Core Cooling control. The following controls are associated with the off- line core cooling system:

a. Inlet and outlet valves from the reactor core to the heat exchangers.

b. Shutdown Circulation Pumps. These use the standard permissives for any pump. This is the suction being open and the discharge closed if there is no pressure on the discharge of the pump. It is critical that the discharge be opened after the pump is started.

c. Shutdown cooling flow indicator for each pump/heat exchanger combination.

d. Temperature indicators INTO and OUT of the heat exchanger.

e. Maximum (calculated) fuel temperature on each loop.

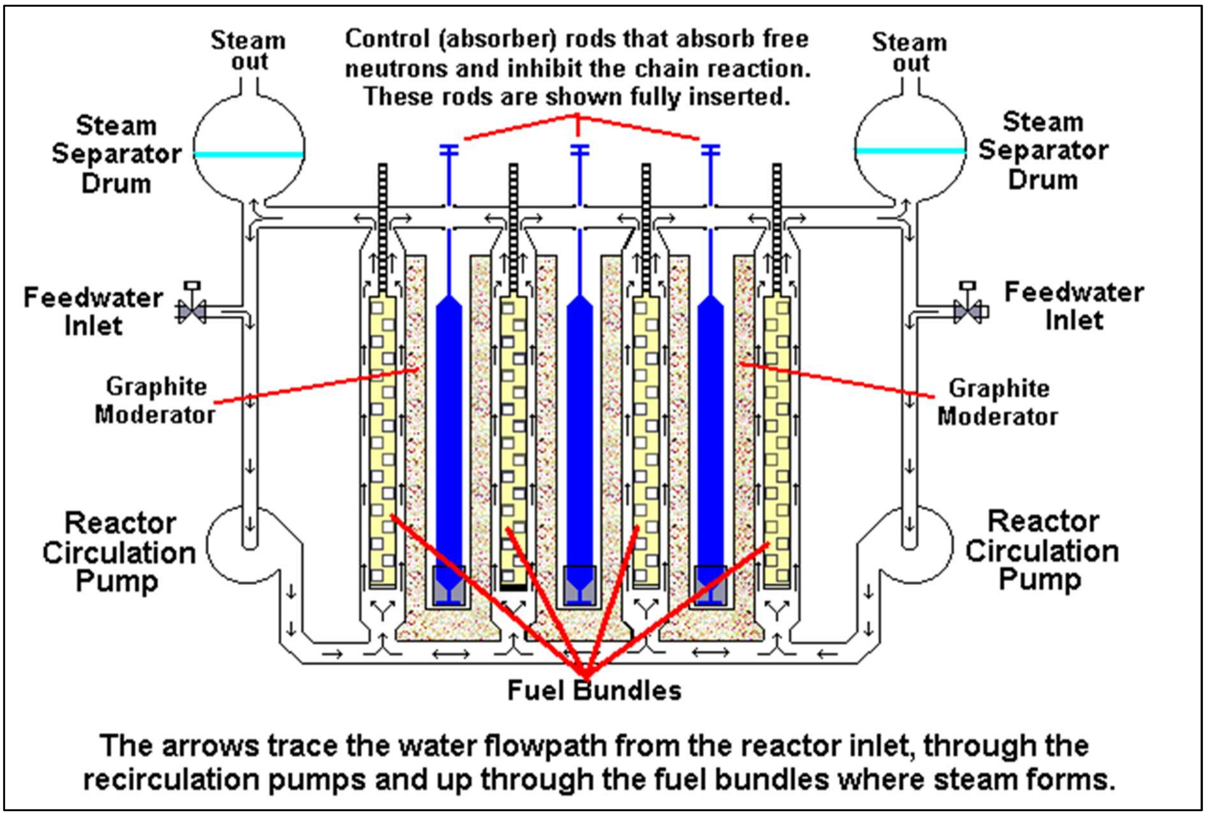


Figure 16: Closeup of the RBMK-1000 Graphite Moderated Reactor Circuit

26. Reactor Steam Separator Drums: These are the steam separator drums for the reactor. They are 60" vessels that form the interface between steam and water in the reactor steam water circuit. Heated reactor feedwater enters the reactor circuit in the separator *downcomer* for each loop. (See figure - 16). This water drops straight into the reactor recirculation pumps and is pumped through the core (fuel pile) where it picks up heat and forms steam bubbles. This water steam mixture then flows out the top of the core (fuel pile) and into the steam separator drums. The steam and water mixture separates in the separator drum and the steam flows to the turbine. The cooler water that did not have steam bubbles in it recirculates back through the core.

The circulation rate for the RBMK-1000 is about 8 to 1. This means that at rated steam flow (8 million pounds per hour) the flow through the core is maintained at approximately 64 million pounds per hour by the recirculation pumps. This is very high and very necessary. It is essential that the steam production in the core be kept below a certain point or proper cooling of the core will not be achieved.

Mechanically. this reactor is very simple. It is just like the tea kettle blowing onto the pinwheel. The water is heated inside the core of the nuclear reactor, and the steam water mixture is separated in the steam separator drums.

In figure - 16 it is important to note the absorber rods that are used to control the speed of the neutron reaction in the core. The absorber or control rods are removed from the core to start the reaction and inserted into the core to stop the reaction. Other items in figure - 16 that should be observed are the graphite moderator blocks, the flow path of the steam water mixture indicated by the flowpath arrows, and the feedwater inlet to the reactor.

Even though there are two drums, there is not separate level indicators for each steam separator drum. There is only a common level indication for both drums on the reactor control and the feedwater control. The normal water level in the steam separator drum is considered “0”. When the level increases beyond the normal level, the number increases in the positive direction. When the level decreases from the normal level, the number increases in the negative direction. The following level alarms and their setpoints are associated with the steam separator levels:

Reactor High Level Trip. This alarm sounds when the level increases to +10". When the steam separators reach this level, you have a serious problem. Draining the level to prevent water in the steam system is essential. At this time the turbine will automatically trip and the reactor will SCRAM.

If the level reaches this high and the reason has not been found or corrected, the reactor feed pumps should be shutdown. If the reactor feed system is still forcing water into the system, the possibility of filling to the main turbine stop valves exists. This can severely damage steam piping, and can lift the safety valves on the separator drums and steam system. This is serious for a number of reasons:

* Thermal shock to the reactor and main steam lines.

* Thermal shock to the turbine valves (the turbine should be tripped by now, and the valves closed. If the turbine isn't tripped, it will be completely destroyed).

* The main steam and separator drum safety valves could open. This creates a large blow of radioactive steam to atmosphere. Since these safety valves are designed for steam and not water they could be damaged and not reclose as designed. This creates a far greater radiation problem as the system blows to atmosphere.

Reactor High Level. This alarm sounds when the steam separator level reaches +4".

Reactor Low Level. This alarm sounds when the steam drum level reaches -4". This is the first warning of a possibly very serious problem. The core cannot become exposed!

Reactor Low Level Trip. This alarm sounds when the steam drum level reaches -10". At this level the reactor will SCRAM, which will automatically trip the turbine, and start the Emergency Reactor Cooling (ERC) system if it is in AUTO. Remember, when the ERC starts, the core is flooded with cold water. This creates a serious thermal shock to the reactor components.

28. Reactor Control (Absorber) Rods: These are the primary control devices of the RBMK - 1000. When inserted in the core the neutrons are absorbed stopping the nuclear chain reaction. The nuclear reaction is started by an operator manually pulling the rods from the core in a very careful, slow, and controlled manner. Once the chain reaction begins, it is exponential. It will get out of hand very quickly. It is critical that the rods not be pulled without continuous and constant monitoring by the operator.

Once the reactor goes critical, the rods require constant regulation to maintain the power level in the reactor core. Unlike the real RBMK - 1000 reactor, our reactor has an automatic power regulator that allows the operator to set the desired power output.

The Reactor Power Regulation panel allows you to place the reactor in an automatic control mode. This is completed by selecting the control block to on by pushing the ON button. Once it is on you can select the desired power level you wish the reactor to maintain by using the mouse to click on the up and down arrow selection next to the power setpoint block. Care must be taken to only change the power setpoint small amounts at a time. Changing power levels too fast can upset the reactor and cause neutron power surges which can "void" the reactor and damage the fuel bundles. To increase reactor power level above 2% requires the steam turbine to be reset.

Resetting the turbine requires the lube oil, hydraulic oil, and the steam seals to be in service and the vacuum system be in service with vacuum pulled on the condenser. (See the Turbine Support Systems and Condenser Vacuum System control blocks). The Reactor Power Regulation panel also allows you to view the neutron rate, the neutron flux, and the neutron flux log. These indicators provide you with different methods of monitoring the neutron activity in the reactor. As these indicators increase, the neutron activity and power level in the reactor increases also. Other panel indicators are fuel burnup that shows how much potential reactivity there is in the fuel. Please understand, this is not the percent of fuel left, it is just the potential reactivity if the reactor is operated properly. In reality, the reactor will lose criticality anywhere between 40% and 20% indication from this block. This is because a sustained neutron reaction requires several factors such as where the *good* or reactive fuel is located at in the core, and what rods are being pulled.

The Reactor Power Regulation panel also allows you to enable and disable the reactor emergency trip (shutdown) systems. When you select reactor safety systems to the off position, the reactor emergency shutdown systems are disabled. This is a very dangerous thing to do. Disabling the emergency shutdown systems was a major part of what destroyed Chernobyl # 4 reactor. Thermal power correction allows the reactor power regulation panel to give the operator a true and accurate indicator of the thermal power level instead of a calculated value based on neutron rate and flux. If you wish to trip or rapidly shutdown the reactor you can select the trip button located in the reactor scram portion of the reactor power regulation panel.

29. Core Helium Radiation Detector. The core helium radiation detector is designed to alert the operator to a possible steam generating tube leak within the reactor core. The design of the RBMK is such that a tube leak is difficult to detect. Since the core of the reactor is filled with graphite moderator (see figure - 16), the areas of graphite blocking are charged with helium. The helium in these areas is circulated through the radiation detector that checks for radioactive iodine. If there are any steam generating tubes leaking, the water/steam mixture will immediately cause radioactive iodine to form in the graphite stacked core areas. This will set off an alarm that indicates a possible tube leak in the core. This is an alarm function only.

30. Main Steam Shutoff Regulator. This is used to isolate the reactor from the turbine for hydrostatic tests, emergencies in the steam system, and maintenance of items in the steam system. There is NO logic for opening or closing this valve. It is operator discretion only. It is recommended that this valve remain open at all times.

31. Turbine Stop and Control Valves. The turbine stop and control valves are precision valves that control the steam into the turbine. These valves are designed to be completely redundant to ensure proper control and stoppage of the steam into the turbine. The Chernobyl turbine uses a main control valve assembly and a startup, or bypass valve assembly. The startup valve assembly is a low flow valve system that allows steam flows up to approximately 20% of rated. Steam flow greater than this require the main valves to be selected.

It is important to remember that the turbine rotor weighs several hundred tons. This rotor is spinning 3,600 RPM. When the generator is loaded to maximum output, there is over 1.5 million horsepower coming from the turbine. The only thing that is holding the turbine at 3,600 RPM is the generator being *synchronized* to the electrical grid. If, for any reason, the generator circuit breaker opens, there is nothing holding the turbine back from going into a massive overspeed. Therefore, the turbine stop and control valves in combination with the speed control system (governor), must react instantly. If they did not the turbine would become a huge grenade exploding into thousands of pieces.

The turbine control valves react to changes in pressure from the reactor to maintain a steady main steam pressure. This is a very important and critical concept that must be grasped to operate the plant effectively. As power output is increased from the reactor, the steam pressure will start to increase. As the steam pressure increases to the operator's desired setpoint. the turbine valves open allowing more steam to pass through the turbine. This increases the electrical output of the plant. If the reactor power output falls, the steam pressure in the main steam system will drop. As soon as the turbine control system senses this pressure drop. the turbine control valves will begin to close. This reduces the amount of steam into the turbine and reduces the electrical output from the generator. Be sure you understand this concept. It will certainly help you later.

The turbine control for the Chernobyl plant consists of a speed and load controller. The speed must be controlled before the generator is synchronized to the power grid and the load is controlled after the generator 1s synchronized to the power grid. The turbine speed and load is controlled by opening the steam valves and admitting more steam to the turbine. This can be accomplished by pressing the manual button and increasing the valves using the up arrow. The turbine must be reset prior to opening the steam admission valves. To reset the turbine you must complete the following:

a. Start the lube oil pump. This control is located under the turbine support systems.

b. Start the hydraulic oil pump. This control is located under the turbine support systems.

c. Place the steam seals on. This control is located under the turbine support systems.

d. Start the condenser vacuum system. These controls are located under the condenser vacuum system.

The condenser vacuum system will not function until steam pressure is available. Therefore, to reset the turbine, the reactor will have to produce sufficient steam to power the vacuum system. This should not be a problem at any time.

Decay heat is usually sufficient to produce the steam necessary for the vacuum system. There are two steam admission valve systems on the turbine. The first is a small bypass system labelled start-up. The startup valves will only pass about 20% of total steam flow. The main valves must be selected for service after the turbine is to 20% load. To roll the turbine to rated speed in auto, select the rate of speed to roll at (slow, medium, or fast) and then the speed you choose to roll to. The roll rate and speed that you roll to depends on the reactor steam temperature and pressure, and the turbine shell temperature. If the turbine is cold, you should pick a slow rate and stop at each pre-programmed stopping points to allow the temperatures to rise slowly. Remember, there is a massive amount of iron in the turbine that must be heated in a slow and reasonable manner to prevent metal stress. The best method is to watch the vibration meter and the differential expansion meter. If you have high vibration or high differential expansion, you should slow down the roll rate or hold at one of the pre-programmed points.

Differential expansion is caused by the rotor of the turbine heating faster than the shell. If this gets excessive, serious damage can occur to the turbine. The turbine control panel is an excellent place to monitor turbine speed, generator load, and reactor drum pressure. The reactor drum pressure is controlled by the turbine valves opening and closing to maintain the pressure setpoint when in auto. To place a pressure setpoint into the control system you must click over the setpoint data field and place your desired setpoint in the field. The turbine will only control to this setpoint if the turbine valves are selected to auto.

The final items controlled from the turbine panel are the generator circuit breaker, and the generator synchro-scope. When the turbine is at or near 3600 rpm you can select the generator synchro-scope to the ON position. It should be rotating slowly in the clockwise direction. You should wait until the scope is less than 6 rpm (quite slow) and then close the generator circuit breaker when the scope gets to 2 or 3 degrees before top dead center. Once the generator circuit breaker closes, you must open the turbine valves enough to place at least 20 megawatts load on the generator. This is accomplished by reducing the pressure setpoint with the turbine valves in auto, or placing the turbine valves in the manual position and selecting them open enough to increase the load. If you do not get the valves open quick enough, the generator circuit breaker could trip (open) to prevent reverse power in the generator.

Reverse power is when power flows into instead of out of the generator. This essentially makes the generator a motor and not a generator. While the generator can function as a motor, the turbine can be damaged if steam flow is not keeping the extremely long low-pressure blades cool.

32. Vent Stack Radiation Monitor. The vent stack radiation monitor indicates the condition of the HEPA filters. When the HEPA filters are in full service (the bypass around them is 100% closed), the radiation will be normal. When the HEPA filters begin to plug, the bypass must be opened or the HEPA filters must be replaced. The more the bypass opens, the more radiation is released to the vent stack. The vent stack radiation monitor is an alarm function only. Please remember that the Ukrainian government can assess some very heavy fines for dumping radionuclides in the atmosphere from the vent stack.

33. Cooling Pond. The cooling pond supplies the water that flows through the plant condenser. This is the water that causes the turbine exhaust steam to condense so it can be re-used in the steam water cycle. The cooling pond at Chernobyl is quite large (it is actually a very large reservoir) and has little fluctuation in temperature from summer to winter.

34. Circulating Water Pumps. The circulating pumps pump the cooling water from the cooling pond, through the condenser, and back to the cooling pond. These are extremely large pumps. They are each rated at 485,000 gallons per minute of flow. This equates to each producing 70% of the needed flow to cool the entire plant at full power output. Loss of one (1) pump (or failure to start both of them at higher loads) will cause an excessive heat build-up in the condenser. This will quickly cause the condenser pressure to increase until the turbine trips, and the reactor scrams. The controls for these pumps are located on the condenser circulating water pumps control. The controls consist of an on and off button for each pump and flow and pressure indicators for the plant condenser. The suction and discharge valves are automatic and function with the pump on and off pushbuttons.

35. Steam Jet Air Ejectors. The steam jet air ejectors use steam to draw the air and other non-condensables from the condenser to ensure that the vacuum in the condenser remains at the highest possible negative pressure.

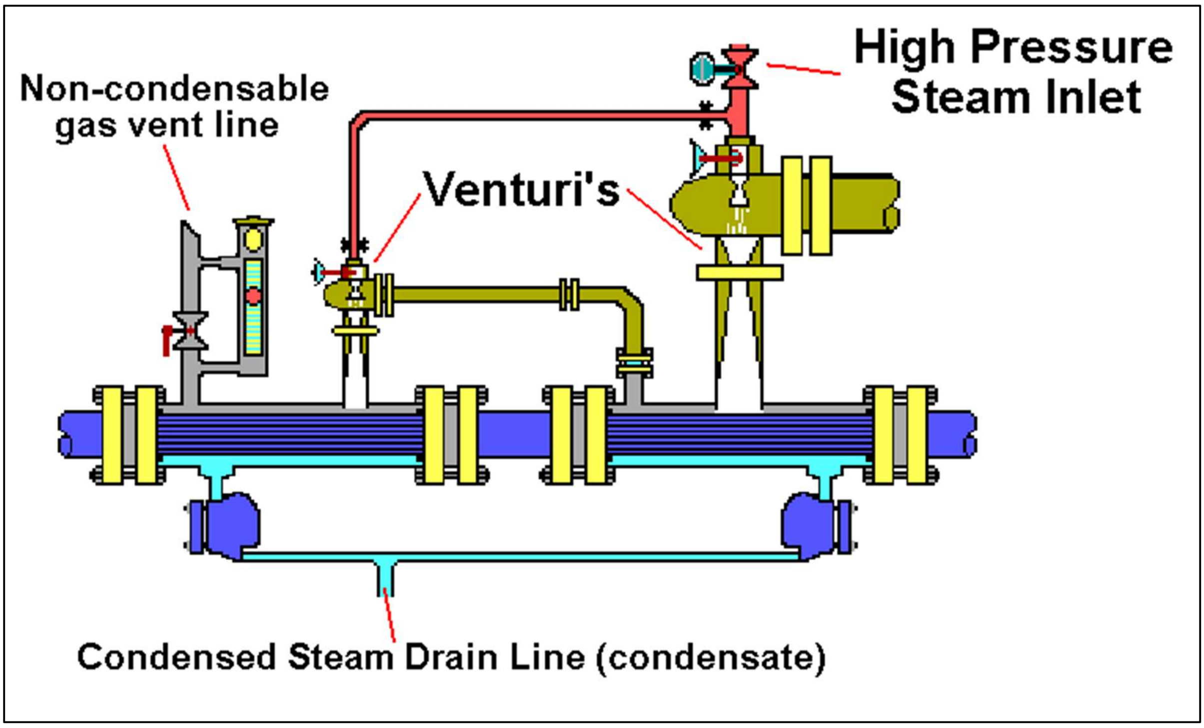


Figure 17: Steam Jet Air Ejector

The steam jet air ejectors use high pressure steam from the main steam line to power steam *venturis*. A venturi is a simple device that increases the velocity of steam through a tapered pipe. See figure - 17.

One law of physics states, 'when velocity increases, pressure decreases". This is a physical law of nature. When steam is accelerated through a venturi, the pressure within the venturi decreases to a near vacuum. These venturis are connected to the condenser via piping.

The venturis negative pressure is greater than the negative pressure in the condenser. Therefore, the venturis, or steam jet air ejectors, draw the non-condensable gasses from the condenser. The steam through each venturi is mixed with the non-condensable gasses from the condenser. Both the steam and gasses leave the venturi and enter the condenser section. The built-in condenser section has cooling water running through its tubes. The resulting condensation draws an even greater negative pressure in the venturis. The condensed steam (condensate) drains to the low-pressure feedwater heater. The non-condensable gasses are vented through vent piping to the HEPA filters where the radionuclides are filtered. The remaining gasses are vented in the vent stack.

7.0
Reactor "Quick" Operational Basics:

Nuclear reactors are extremely complex in their interactions. People go to school for extended periods of time to understand the complex interrelationships of nuclear power and nuclear theory. However, we are going to cover only the very basics of reactor control here. We are going to bring it to a practical level of what you must do to control the reaction within the reactor to make steam for the turbine.

A reactor is nothing more than a nuclear pile that contains fissionable material (uranium) and an environment that promotes neutron activity. In its easiest to understand form, neutrons collide with the uranium atoms causing them to split and give off energy. See figure - 18 below.

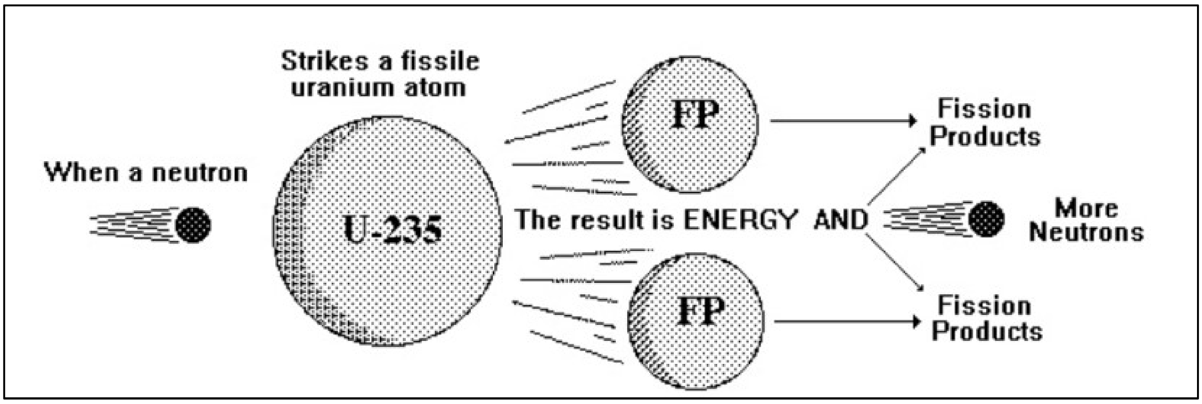


Figure 18: Fission at a Glance

The environment in which this activity occurs is called the moderator. The RBMK reactor uses graphite as a moderator. Graphite slows the neutrons down without absorbing them. This is a key element for a reactor. If the neutrons are too fast, or if they are absorbed before they strike the uranium, they will not split the uranium atom. We must therefore slow down the neutrons so they have a chance to split the uranium atom and produce energy. If we absorb the neutrons the reaction will cease.

As a very simplistic statement to help understand what is taking place, the free neutrons are what produce the heat in the reactor. Although it is actually the uranium atoms that are producing the vast majority of the heat, they could not do so if not split by the neutrons. The more neutron activity the more heat produced in the core because more uranium atoms are being split.

Self-sustaining nuclear fission is when a free neutron splits a uranium atom causing energy release and also releasing an additional neutron that goes forth and splits another uranium atom. This in turn frees up another neutron to split another atom and the process continues.

The problem with this is the degree of control that we have. Since we are talking about millions of neutrons and millions of uranium atoms, this chain reaction can get out of hand very quickly. We have to provide something controllable to maintain the number of free neutrons. Therefore, we place removable rods in the reactor that absorb the neutrons. The absorber rods absorb the fission producing neutrons and slow or stop the nuclear chain reaction.

There are other methods of stopping the neutron activity in the core. One of these is with neutron inhibiting compounds such as boron. Anything that absorbs neutrons is called a reactor poison because it slows the reaction. The reactor itself will quickly build-up poison compounds if mis-operated. In the Chernobyl style RBMK reactors, un-enriched uranium is used. When operated at reduced power levels there is a build-up of xenon (pronounced zenon) gas. Xenon gas was a major part of the accident that destroyed Chernobyl unit - 4. They were operating the reactor at partial power levels during the rolling inertia test. During this time xenon was building up, inhibiting neutron activity. This is what is known as poisoning the reactor. The Chernobyl RBMK reactor must be operated above 60% power or xenon poisoning will occur and shut the reactor down. Recovery from xenon poisoning is a matter of shutdown time (up to 36 hours) to allow the xenon gas to decay.

In summary, as the neutron flux increases, the heat increases. As neutron flux decreases the heat in the reactor is reduced. We have already discovered that the RBMK reactor has a high positive void coefficient. This means the hotter the reactor gets the more neutron activity that occurs creating more heat. This is a very poor design flaw in any reactor. The safest way to design a reactor is to build it so that the hotter the interior of the reactor gets, the less neutron reactivity occurs. This 1s a negative void coefficient. Since we have to live with the design of the RBMK, lets cover how to control it.

Reactor Controls:

First and foremost, you must keep cooling water in the reactor. The reactor water level absolutely MUST be kept at normal operation levels. This is the single most fundamental and critical item of reactor control. Under no circumstances should the water level be allowed to drop below the drum level. An uncovered fuel bundle is the most devastating of all accidents. When a fuel bundle is uncovered, it will very quickly overheat and melt. This is where the term “melt down” is derived from. Once this begins, the reactor is probably unrecoverable. This is because the fuel is housed, or clad in a zirconium alloy. When melted it gives off hydrogen gas. Hydrogen gas is quite explosive.

There are two (2) backup systems on the Chernobyl reactor for water addition. The primary backup system consists of two (2) electric driven pumps, and the secondary system consists of a diesel engine driven pump. Either of these systems are designed to maintain water level in the reactor. The water pumped by these units is straight from the condensate storage tanks. Since this water is unheated, the reactor can receive serious thermal shock when the emergency core cooling system is placed in service. It should be used for emergency purposes only.

Secondly, the reaction will stop if the neutrons are absorbed. They can be absorbed by pushing the absorber rods into the reactor vessel allowing the rods to absorb the neutrons before they strike the uranium atoms. This is how the RBMK reactor controls itself and also shuts itself down. The absorber rods are systematically pulled to begin the reaction. The reaction is controlled by the amount and number of neutron absorber rods inserted into the reactor vessel.

The absorber rods should always be pulled slowly and carefully. Quick absorber rod pulls have caused serious incidents to occur in reactors of all types, including the RBMKs. Rod pulls should be slow, deliberate, and controlled actions that require the operator to closely monitor the reactions. Neutron rate, neutron flux, and thermal power must be watched very carefully during any rod pulls.

The neutron rate will be the first and most visible sign that you are changing the amount of neutron activity in the reactor. On the reactor absorber rod control grid you can monitor the neutron activity directly under the selector switch labelled PULL RODS. You can also watch neutron activity on the reactor thermal power regulation panel in the area labelled neutron rate, neutron flux, and neutron flux log. The greater the (positive) number, the greater the reactivity in the reactor.

8.0
Reactor Refuelling

This game, like the Soviet RBMK - 1000 reactors, refuels on-line. Fuel status and burn up is monitored in two (2) ways. The first 1s the fuel burn up indicator located on the reactor power regulation panel. This tells the total fuel burn up status. Since the fuel burn up in a reactor is not linear you can actually lose criticality with as much as 40% fuel. This is because there is a flux pattern established in the reactor during operation. Some areas of the reactor tend to burn the fuel quicker than others. When the reactor flux pattern is highly imbalanced, it is possible to lose criticality when certain parts of the reactor core have used their fuel, even though there is adequate fuel loading in other parts of the reactor. You should use the Geiger Counter located on the bottom of the reactor control rod matrix to determine the fuel burn up. See Figure - 19 below:

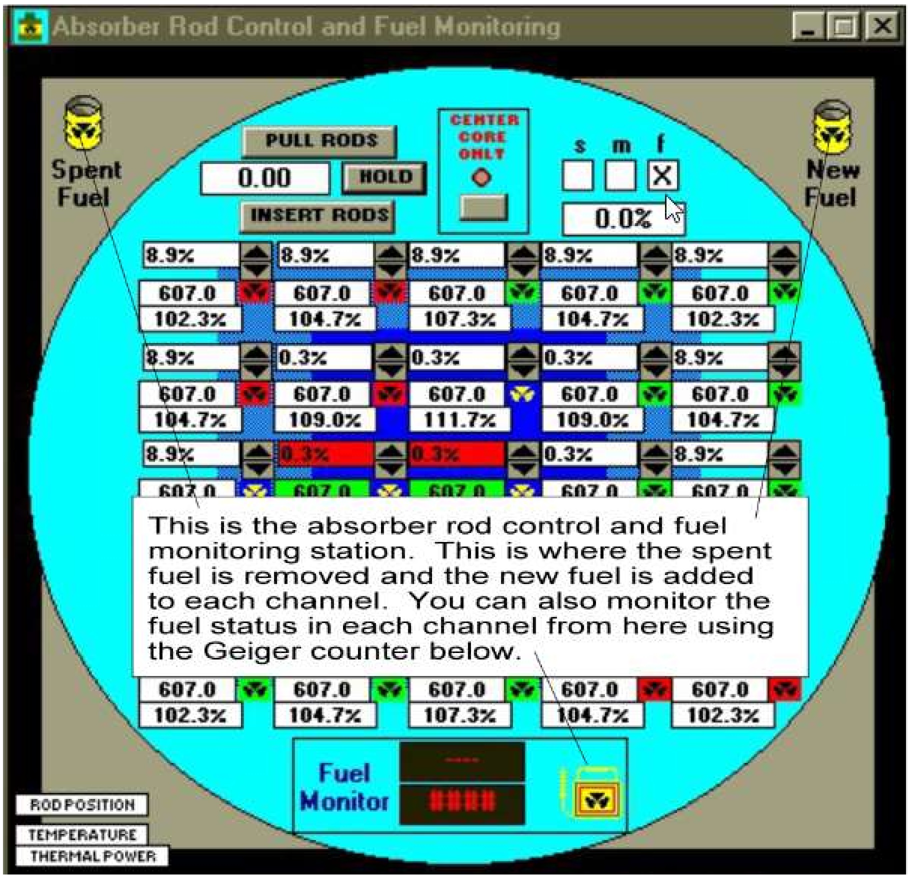


Figure 19: Reactor absorber rod control matrix

To determine how much reactivity is left in the fuel, move the mouse over the top of the yellow Geiger counter located in the Fuel Monitor section of the absorber rod matrix. Click and hold on the left key when on the Geiger counter and move it carefully over the fuel bundle you wish to check. When you are located properly over the bundle it will turn blue. This is your indication that it is okay to release the left mouse key. When you release the left mouse key, the fuel monitor will display the amount of reactivity still available in that fuel bundle.

You should use as much reactivity from the fuel bundle as possible to maintain your budget. Changing fuel too soon costs you in three ways... The first is the loss of use of the existing fuel. When replaced too quickly, energy that is still left in the fuel is lost. The second is the spent fuel storage costs. Since the spent fuel is highly radioactive it must be stored for several hundred years. This storage and handling cost is substantial and “dings” your budget heavily. The third is the actual cost of new fuel. Obviously, when new fuel is installed, you have to pay for it.

When it is necessary to refuel a channel, extreme care must be taken. You must first remove the depleted fuel by moving your mouse over the top of the designated channel and clicking on the left mouse key. You must then move the mouse, while holding firmly upon the left mouse key, over the barrel that is labelled SPENT FUEL on the matrix. After positioning the mouse directly over the top of the SPENT FUEL barrel, you can release the spent fuel into the spent fuel holding area. If you “miss” or release the left mouse key prior to positioning over the spent fuel barrel a large budget expense will occur from mis-handling the fuel. This is because a mis-handled fuel bundle incurs extensive clean-up costs.

To add new fuel to the reactor you must first remove the depleted fuel from the channel as described in the previous paragraph. Once the depleted fuel is deposited in the spent fuel barrel you must position the mouse over the new fuel barrel. While directly over the top of the new fuel barrel, click and hold the left mouse key. While holding the left mouse key, move the new fuel bundle to the reactor channel that you previously removed the depleted fuel. When the channel turns blue, release the left mouse key to deposit the new fuel in the channel. As with removing the depleted fuel, if you release the mouse button prior to positioning directly over the channel, a fuel clean-up cost will be incurred. You will also be charged for a new fuel bundle to replace the ruined fuel bundle that you dropped. Proper positioning is essential to maintain the budget during a refuelling operation.

NOTE: The best indicator of when to refuel is the position of the absorber rods. If all of the rods are almost 100% of the way out, you are very close to losing criticality. When all absorber rods reach 100% saturation you will lose criticality. This is logical because the rods control the reactor power output by absorbing neutrons. When fuel reactivity decreases to the point where the absorber rods are no longer needed, there is not enough reactivity to maintain a chain reaction. At this time the reactor power will fall very rapidly to less than 20% power.

Once the reactivity and power level drops because of fuel depletion you will probably not be able to quickly restart the reactor due to the build-up of xenon gas in the core. Attempts to quickly refuel may increase reactivity, but there is an extreme danger of an out of control reaction due to an exponential power increase to overcome the effects of xenon poisoning.

As always, be very wary of trying to restore criticality after it has been lost, even if it is for a short period of time. Do not underestimate the effect of xenon poisoning. This is the mistake the operators of the doomed # 4 reactor made in 1986 when the disaster occurred.

9.0
Steam Turbine Basics

Chernobyl Steam Turbines

A steam turbine is actually a very basic device. It is nothing more than a rotating, mechanical, energy transfer machine. It simply takes heat energy in the steam and turns it into rotating mechanical energy necessary to drive a generator.

Some view a turbine as a pressure device. However, this is not accurate. A turbine is a heat device. It appears to be a pressure device because the pressure in steam drops as heat is removed. Therefore, as heat is removed throughout the various stages of the turbine, the pressure drops. It is the heat energy in the steam doing the work, not the pressure.

Steam flows into a turbine through inlet valves that stop and control the steam flow through the staging. After the inlet valves the steam flows through a nozzle block. This is a stationary device that evenly distributes the steam onto the first stage of the turbine. A stage in a turbine is a set of rotating blades that is located between stationary vanes that direct the steam. Figure - 20 is the rotating portion of the turbine. This is usually referred to as the turbine rotor. In between the rotating blades shown in this figure are stationary blades that redirect the steam flow onto the next set of rotating blades. The combination of one set of rotating blades and one set of stationary blades makes one turbine stage.

The steam enters the turbine through a series of hydraulically opened, spring closed control and stop valves.

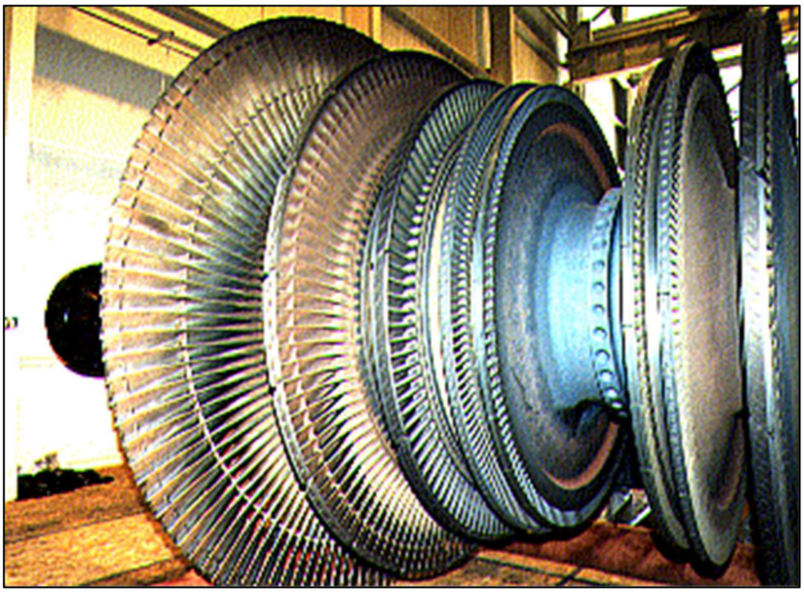


Figure 20: Turbine Rotor

These valves are spring closed for safety reasons. Anytime there is a serious problem that requires immediate shutdown of the turbine, the inlet valves are *tripped* closed at a very rapid rate. The closing of the valves is not dependent upon the hydraulic system. It is necessary to build turbines this way for safety reasons. A steam turbine must be able to stop steam flow extremely fast. This is because there is a high potential for a destructive overspeed if the generator circuit breaker opens when the turbine generator is carrying load. We will cover the electrical theory of the generator in the next chapter. However, for now you must accept that if the turbine did not have an extremely rapid valve closing system, you could easily scatter the turbine over the countryside. It has, in fact, happened more than once.

Figure 21 is a turbine shell and the associated steam valves. Notice how large they are in comparison to the turbine. This is because they must handle high pressure and temperature steam and must be relied upon to close extremely fast in the event of an emergency.

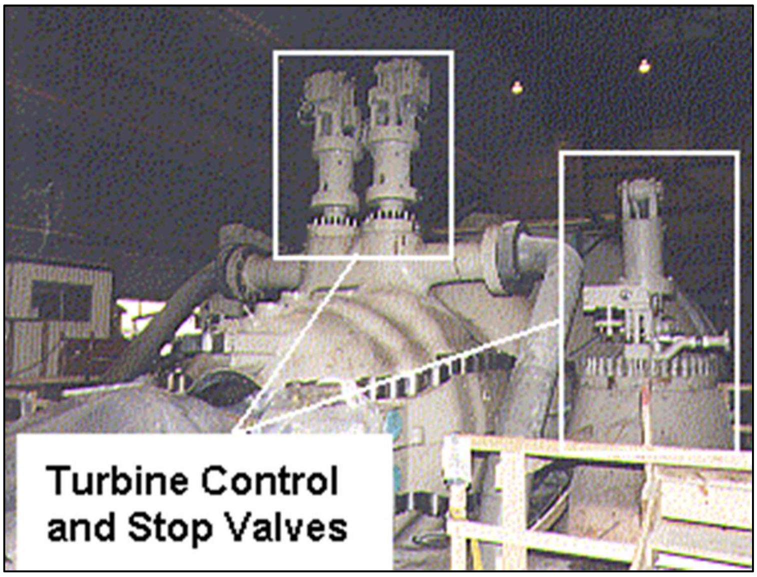


Figure - 21

The first stage of the turbine is the highest pressure and temperature stage. As the steam gives up energy in the blading, the pressure and temperature decrease. This causes the volume of steam to increase because as the pressure and temperature decrease, the density of the steam increases. Therefore, the staging in the turbine gets larger and the blades get longer as the steam continues its path through the turbine. The longest or biggest blades extract the least amount of energy. The smallest blades do the most work because there is so much energy available in the steam.

The steam must be directed through the blades because steam, like most substances, takes the path of least resistance. Therefore, there are several different sealing processes used to prevent the steam from bypassing the preferred path. There are generally seal strips at the blade tips and on the rotor between stages. These seals prevent the steam from escaping the blade path without doing any work. Figure - 22 is an enlarged view of turbine steam seals. Turbine seals are generally metallic labyrinth type seals. This means that they are very close clearance metal high/low strips that provide a tortuous path for the steam to get through. Simply put, a turbine seal creates a steam path that is more difficult and resistive than the main steam flow path through the blades.

There are two major types of steam seals or packing. The first prevents steam from bypassing the internal staging of the turbine. This is called interstage packing. The second prevents the steam from escaping out of the turbine shell to the atmosphere. This is called atmospheric packing. Since the turbine rotor must come out of the turbine casing on both ends of each section, a special set of seals or packing must be used in these areas.

Interstage packing does not require a steam supply or leakoff because everything is internal to the turbine. The atmospheric type seals require a steam supply to provide resistance to the steam trying to leak out, and a leakoff system that captures the steam that does escape from the casing atmospheric seals. Anytime there are large temperature differentials in the turbine, the first area that can have metal to metal clearance problems are steam seals. A typical labyrinth steam seal is illustrated in figure - 22.

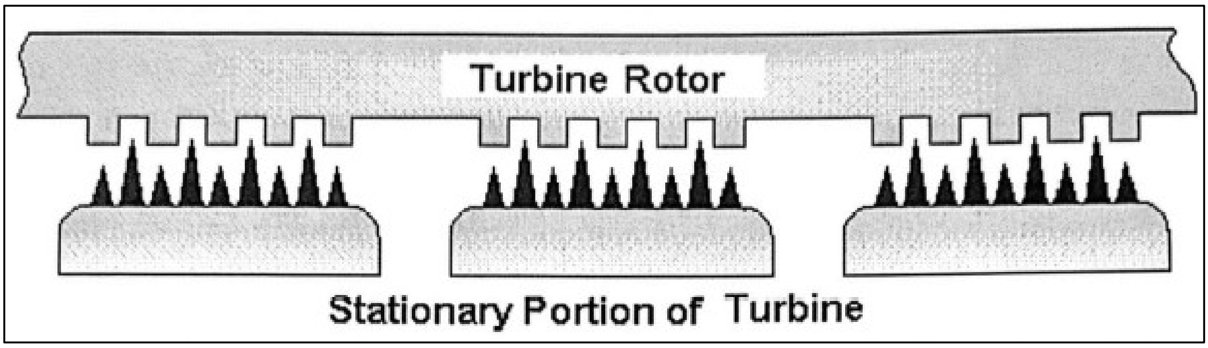


Figure 22

Steam turbines usually have very close tolerances between the stationary and rotating blading. This is necessary to increase the efficiency of the turbine. Anytime you have a very large rapidly rotating mechanical device with minimal clearances between the parts, you have the potential for serious damage if something rubs. Since we have already covered that a steam turbine is a heat device and not a pressure device, we must be careful to limit the rate and the amount of temperature change within the turbine during operation.

Since the rotating portion of the steam turbine is not connected to the stationary portion, rapid changes in steam temperature can cause the rotating portion to expand or contract quicker than the stationary portion. This can cause severe problems in a steam turbine if this growth is not controlled. We call this expansion and contraction *differential expansion*.

Differential expansion on the Chernobyl turbine is indicated on the turbine controls section. If you change steam temperature too fast the turbine rotor tends to thermally expand or contract quicker than the heavier shell section of turbine. This is most noticed during rapid or large changes in the turbine power output. As the steam flow through the turbine is increased or decreased, the temperature within the turbine changes. This temperature change almost always affects the turbine rotor first. As a general rule, limit the amount and the rate of load (power) changes as much as possible. Too fast, or too much of a change all at once will cause high differential expansion in the turbine. This differential expansion, if severe, will trip the turbine, and if too severe, cause extensive damage to the rotating and stationary portions of the turbine.

Steam turbines require several subsystems for operation. The major support items that must be provided on a steam turbine are:

* **A lubrication oil system with sufficient cooling capacity to remove the heat generated in the bearings.** This system always has an emergency backup, usually in the form of a battery driven DC oil pump. This is necessary to maintain lubrication while the turbine rolls down from rated speed. It is important to remember that a large steam turbine like Chernobyl's can take as much as two hours to roll down to a stop. This is because of the massive weight of the turbine rotor. It is like a large freight train... It has a tremendous amount of momentum. Anytime the primary oil system is lost or shutdown, the turbine will trip, allowing roll down of the turbine on the backup system. Figure 23 shows typical turbine lube oil pumps.

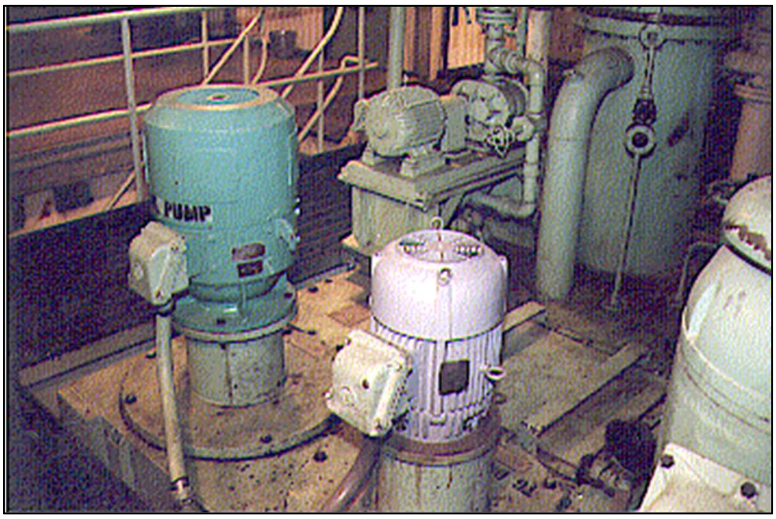


Figure 23: Turbine Lube Oil Pumps

* **A hydraulic oil system for operation of the turbine control and stop valves.** Some turbines use a portion of the lubricating oil system for the control oil. However most use a completely separate oil system with external hydraulic oil pumps.

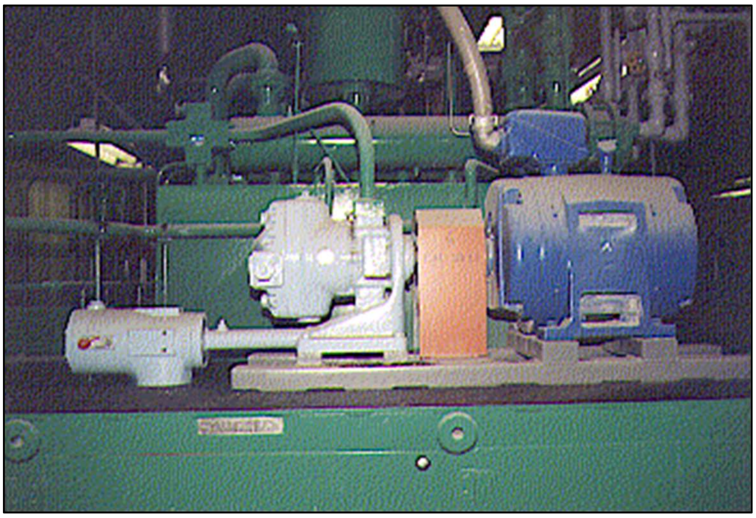


Figure - 24: Typical Turbine Hydraulic Oil System

Since the hydraulic oil system holds the turbine valves open against the pressure of the large springs trying to close the valves, the turbine will trip anytime the hydraulic oil system is tripped or shutdown. Figure - 24 is a typical hydraulic oil system.

*** A turning gear system that slowly rotates the turbine prior to start-up and after shutdown.** This system prevents the extremely long and heavy turbine rotors from bowing due to the high metal temperatures inside the case. Interestingly enough, a hot turbine rotor will bow upwards, and not downwards. This is because the massive iron that comprises the rotor will expand on the upper side because the heat in the casing tends to be higher on top than on the bottom (heat rises). As the top half of the rotor expands, the force on the rotor creates an upward bow.

Figure 25: Turbine Turning Gear

*** A steam seal steam supply and leakoff system for the steam seals that prevent steam leakage from the turbine case to the atmosphere.** By catching the leakoff steam and routing it through a heat exchanger, the efficiency of the plant cycle can be increased.

*** A drain system that prevents water build-up in the turbine.** These drain valves must be opened during a startup and shut down to prevent carrying slugs of water into the turbine causing damage to the stationary and rotating components. Water contacting the high temperature stationary and rotating portion of the turbine can cause serious damage to the turbine and its components. Keeping the drains open on start-up and shutdown is very important.

*** A control system that allows the operator to control the speed and load of the turbine.** This control system is often referred to as the governor system. The turbine is accelerated to rated or synchronous speed using the speed control portion of the turbine controls. Once the generator circuit breaker is closed, the generator is electrically locked in speed to the electrical system. This prevents the turbine from increasing in speed. Opening the turbine control valves increases the steam into the turbine and horsepower into the generator. This increase in generator horsepower increases the power output of the generator but not the speed. This portion of the control system is called load control. Should abnormal events occur on the power system, or should the generator circuit breaker open, the speed of the turbine generator is no longer locked to the power system. This means that all of the horsepower the turbine is producing has no place to go. If the turbine control valves did not close extremely fast the turbine would be scattered over the countryside due to a destructive overspeed. Figure 26 is part of a typical turbine control panel.

* A condenser or exhaust steam system that rejects the unusable heat (called the latent heat of vaporization) from the steam at the turbine exhaust. If the condenser does not have adequate cooling water or if the condenser vacuum system is not working properly the turbine will trip.

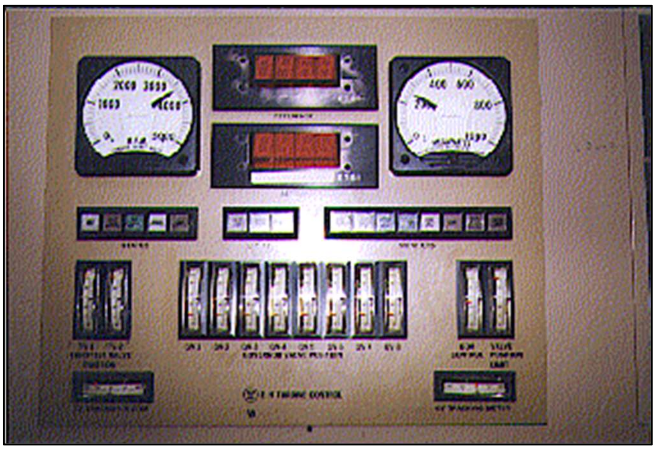


Figure 26: Typical Turbine Control Panel

This is because the turbine is designed to be operated only with a very high negative pressure in the turbine exhaust stages. If this vacuum is decreased too much or lost completely, the turbine efficiency is greatly reduced, and heating of the low-pressure turbine stages occurs. If the pressure in the condenser increases too much (even after the turbine is tripped) an emergency high pressure rupture diaphragm on the condenser will blow. This is necessary because the condenser in a plant like Chernobyl is extremely large and is designed for negative pressures and not positive pressures. The rupture diaphragm prevents a potentially explosive accident from occurring. This diaphragm is a very expensive repair job.

Each of these systems must be in service prior to starting or operating the turbine. Loss of one of these systems will cause the turbine to trip, and will shutdown the entire plant. This is a very brief and minimal explanation of turbine construction and operation. Remember, the actual Chernobyl operators may not have known much more about turbine operation than you do now... Kind of scary isn't it.

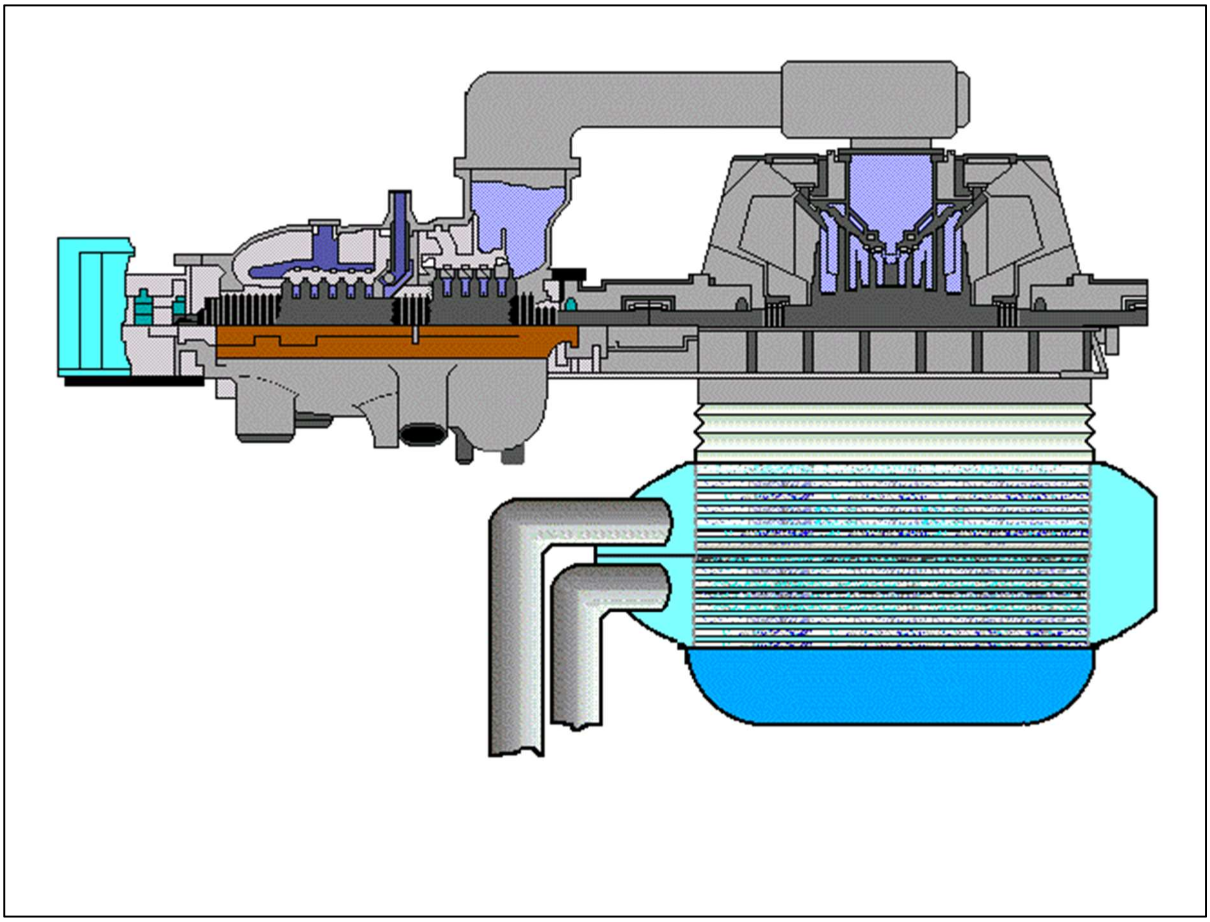


Figure 27: Turbine and Condenser

10.0

Generator and Electrical Basics

There are many excellent basic electricity courses in bookstores and libraries all over the world. This section is not designed to be a full basic electricity course. It is designed to help you understand the electrical operation of the Chernobyl generator.

I must emphasize that in 25 years of dealing with the electric utilities in many different countries, electrical understanding is very poor in this industry. Most think that operators in an electrical utility plant have a great deal of electrical understanding. They usually do not! The process of generating electricity is mostly a mechanical process. The generator itself (not the turbine) has very few controls on it. The operator controls the power output of the generator by controlling the amount of steam into the turbine. One of the few controls that the generator does have is voltage. This is controlled by the excitation system. If you understand the basic precepts of a generator, the electrical portion of the plant is easily learned.

Understanding basic electricity is largely a function of understanding a simple magnet. Natural magnets are found in nature all over the world. Many children are exposed to and play with magnets such as the one in figure - 28.

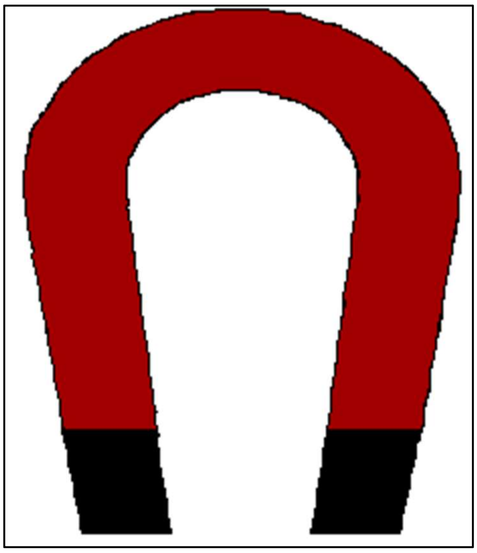


Figure 28: Simple Magnet

A compass is nothing more than a suspended magnet that aligns itself with the magnetic north and south pole of the earth. This is a very critical point when learning how generators work. Magnets have a north and south pole.

If you place two magnets close to each other with the north and south poles closest to each other, the magnets snap together. However, if you try and force two north or two south poles together, it is quite difficult. This is a fundamental statement - Opposite poles of a magnet attract, like poles of a magnet repel.

If we lay a magnet on the counter and dust it with iron filings, the filings will arrange themselves according to the lines of magnetic flux. See figure - 29.

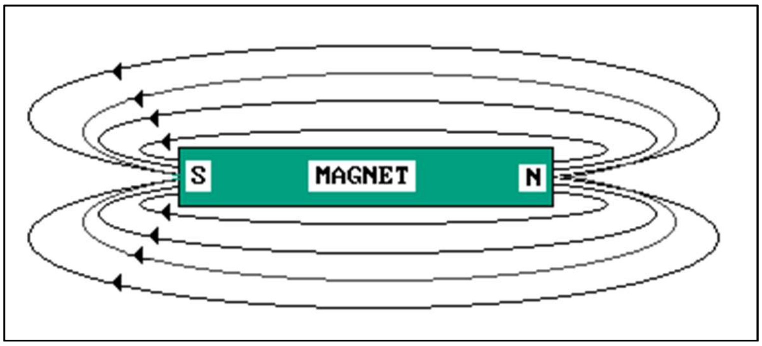


Figure - 29: Lines of Magnetic Flux

These lines of flux are very powerful. When these lines of flux are severed by passing a metallic object through them, an electrical current is generated. This is the basis for building an electrical generator. By breaking the lines of flux in a magnetic field, electricity is generated. Figure - 30 is a generator that is built using natural magnets to provide the magnetic lines of flux. The magnets in this illustration are stationary and the rotating portion of the generator, called an armature, is where the power is taken out of the generator. The magnetic lines of flux can be seen in figure - 30. The rotating armature cuts these invisible lines of flux. This induces voltage and current on the spinning portion of our generator. The problem with this generator is that it is very impractical. The permanent magnets do not allow us to control the voltage from the generator. When current is produced by the spinning action of the armature, the power generated must be taken out of the generator by brushes.

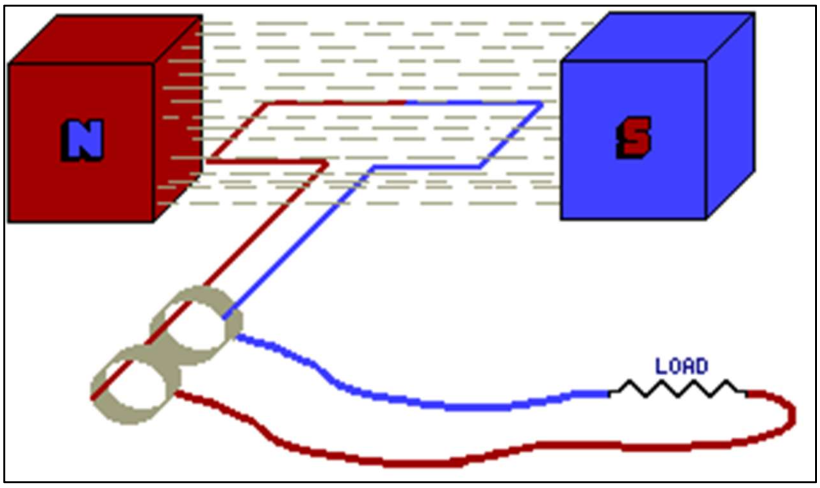


Figure - 30: Basic Generator Constructed with Permanent Magnets

On large commercial utility generators these brushes would be massive and would wear out very quickly. Therefore, it is necessary to use a large rotating electromagnet to ‘produce the field for our generator and allow the power to flow out of a stationary portion. Besides this, natural magnets are not practical to build a generator with. Their limited amount of magnetic flux would require a generator be many times larger than they currently are to produce a set amount of electricity. Without exception, commercial power generators use electromagnets internally to produce the rotating lines of magnetic flux needed for power production.

A simple electromagnet can be constructed by coiling copper wire around an iron bar and then applying direct current to each end of the copper wire. See figure - 31. Electromagnets can be built to be very powerful. Large iron and metal operations use electromagnets to pick up iron and car bodies. This is because they are so strong. Direct current (D.C.) is used to build electromagnets because alternating current (A.C.) will not work.

Using an electromagnet to build a generator allows us to control the output voltage of the generator. This is because we can control the amount of magnetic flux produced in the electromagnet by controlling the voltage into it. If we increase the voltage into our electro-magnet when it is spinning in a generator, the voltage out of our generator will also increase. Let’s look at a basic generator that uses a rotating electro-magnetic field to produce electricity. See figure 32. In this figure we have turned our simple electromagnet in figure 31 into a *rotating electromagnet*. We then place the rotating electromagnet, which we will call the rotor, into a stationary armature which we will call a stator, we now have the basis for all modern commercial electrical generators. The rotor still has a north and south pole. This has not changed.

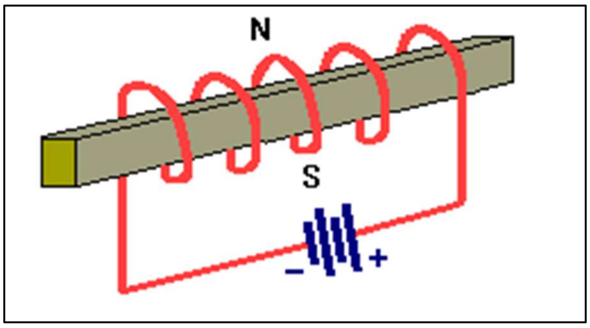


Figure - 31: Basic Electromagnet

What changed is the way we cut the lines of magnetic flux to make electrical current. In figure - 30, the magnetic field was stationary and the armature cuts the lines of flux when it spins. As you recall, this means that the power produced must flow out of the generator on brushes. By making the magnetic field spin and the armature stationary, the power can flow out of the generator without brushes. The only place brushes are required is to provide the direct current (D.C.) voltage into the field to make the rotor magnetized. This is a very small amount of power compared to what the generator produces. Therefore, the brushes to provide the field voltage are very small and relatively trouble free.

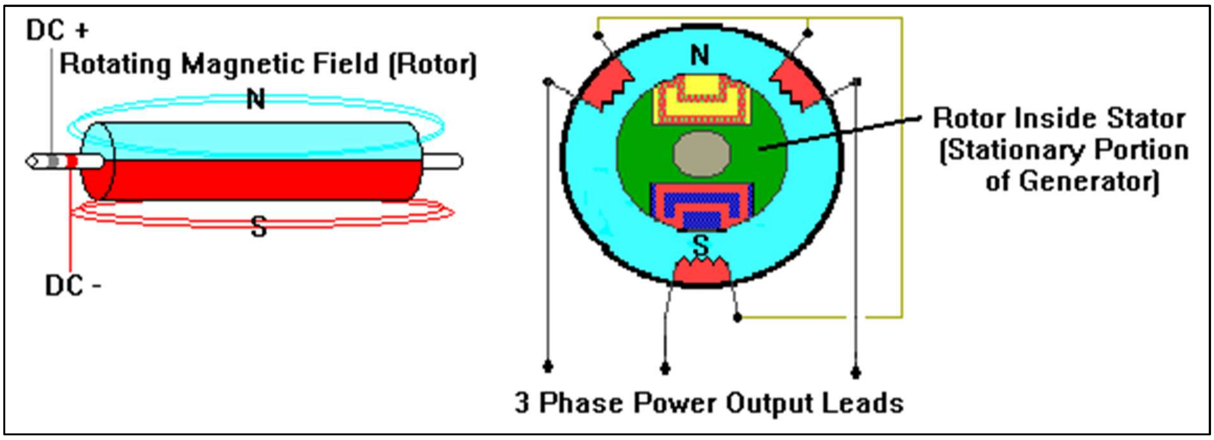


Figure 32: Rotating Magnetic Field Inside a Generator

In figure 32 we see the rotor inside the stator. As it turns, the lines of flux are broken by three separate set of windings. Windings are the term for the coils of wire that make up the generator components. The reason for three sets of windings, each 120° apart is because all commercial power generators produce three (3) phase power. When you look at a high voltage line, you usually will see three (3) separate conductors, or wires, carrying the power. This is three (3) phase power. Most homes have three (3) phase power into the circuit breaker or fuse box and then single phase power into the 110 volt outlets in the house. However, if there is an electric range or an electric dryer, it will most likely use three (3) phase power.

The voltage output from a large utility generator is based on the design of the generator and how much D.C. voltage the operator is putting into the rotating magnetic field.

This is one of the few things that the operator actually controls on the generator. If the operator increases the D.C. voltage into the rotating field of the generator, the output voltage of the generator also increases. There is a limited range of voltage change that an operator has control of. If the operator changes the rotating field voltage too high or too low, the generator will trip (emergency shutdown) to prevent damage to internal components or damage to the power system components.

All electric utility plants use transformers to step-up or step-down the voltage as needed. This allows the power system to use many different voltage levels as needed to improve transmission and efficiency. A typical utility generator may generate the power at 22,000 volts. This will immediately be boosted by a transformer to a much higher voltage for efficient transmission. You see, as the voltage is increased in a transformer, the current is decreased. This means that the conductors of a transmission line can be much smaller, and cost less. When the power gets to your house, it has probably been through several transformers. It will also go through a small transformer that will drop the voltage down to 220 volts for household usage. The reason that your standard wall outlet is approximately 110 volts, is because we only use two (2) leads of the three (3) phase power coming into your house. This effectively drops the voltage by 50%.

We have covered how we produce and control the voltage of a utility generator. So how do we produce the current? Voltage without current can do no work. It is called static electricity. It is not particularly useful for much of anything. However, when you combine voltage with amperes (amps, or current) you then have a product that can do useful work. In fact, watts are the measure of how much work is in electricity. Watts are a measure of power. To have electrical watts we must have a combination of voltage and current. If we have 120 volts and one (1) ampere of current, we have 120 watts. This is because volts x amps = watts. A standard 60 watt light bulb in your home will use approximately 1/2 ampere of current. This is because there are 120 volts. 120 x 1/2 = 60 watts. Current is produced by the amount of horsepower put into the generator. This is the only single method that we can get watts out of a generator. We must put horsepower into it. The harder the turbine turns, the more power is produced. Did you notice that I said harder and not faster? Once the generator is brought to rated speed (3,600 rpm in the United States) we can *synchronize* the generator to the electrical grid. The electrical grid, or power system is rated and running at 60 hertz, or cycles in the United States.

The electrical frequency is maintained by the power system operators on the electrical grid. It is up to them to ensure that no more electricity is dumped into the power system than is being used. If generating plants produce more power than the power system currently needs, the electrical frequency will increase. This means that the speed of everything on the electrical system will increase, including the electrical generators. This also causes the voltage to increase. If there is not enough electricity put into the power system due to more demand than generation, the electrical frequency of the system will decrease. This will slow down everything running on the electrical system including the generators. This will also cause the voltage to decrease. This is what causes the infamous *brownouts* in areas where the power system is heavily loaded, and the demand is high.

Since the electrical grid is so large, a generating station must bring its generator's speed to the electrical speed of the power system and then parallel (or synchronize) to the running power system. Failure to do this correctly can cause damage (possibly severe) to the generator. This is because one individual power plant on a system that has several hundred connected must match the exact electrical speed of the rest of the plants tied together on the system.

An easy way to understand this principle is to look at a small scale version of this. Let's consider a small, gasoline powered, portable electric generator. If we plug a standard light into it, the engine will have to work harder to keep the light lit than when it was not powering anything. If we plug an electric drill into it, it will open the engine throttle each time you press the button on the drill. This generator is trying to maintain its electrical frequency at 60 cycles. If you plug another light, and an electric heater into this generator, the throttle to the gasoline engine will continue to open to maintain the generator at its rated speed and the electrical output at 60 cycles. If you plug too much into this generator and the engine's throttle is already wide open, the generator will slow down and the voltage will drop. The light will dim, the drill will slow, and the heater will put out less heat. You are now trying to use more power than what is available. Energy in = energy out. You cannot use more power than you are producing.

If, after we have our lights, heater, and drill operating, we shut them all off at once, the engine throttle will have to close very quickly or the portable generator's engine will rapidly increase in speed. This is because the throttle is open supplying enough gasoline to the engine to do the required work of the drill, heater, and lights. When you stop using energy in the drill, heater, and lights there is too much energy being produced for what is being used. You are now trying to put more power into the system than what is needed. Energy in = energy out. You cannot generate more power than you are using. The extra energy will just make the engine speed up until the throttle closes, or until it destroys itself, whichever comes first.

What you must remember is this... The POWER out of the generator is controlled by how much steam you put into the turbine. This is because energy in = energy out. The voltage out of generator is controlled by the operator controlling how much D.C. voltage is put into the rotating magnetic field in the generator.

11.0

Step by Step Plant Start–up Procedure

If you trip or shutdown the plant and wish to restart it, you should follow an operational procedure. The problem with an operational procedure is it can't cover even a fraction of the scenarios that can occur from equipment malfunctions, control failures, and other similar problems. Therefore, the procedure provided here is a standard procedure that lists the major steps in bringing the Chernobyl Plant on-line. You will still have to make decisions based on malfunctions and failures of the plant systems and equipment.

As always, you can save where you are at for later usage anytime you choose. The procedure for saving a game and calling it back up later is explained on page - 14 of this manual. This start-up procedure is assuming that all equipment is off except the off- line core cooling system. With this, let's look at the procedure:

1. Optimise your screen views so that you can view as much pertinent data as possible. This includes using the SCHEMATICS section of the pull down menus. There are several important and information laden schematics of the plant systems in this menu section. One of them in particular, the OVERVIEW, gives you the flows, pressures, temperatures, and other pertinent data based on the one line diagram of the Chernobyl plant. Use these displays as needed to track the condition of your plant and its major systems.

2. You should select DISPLAYS and then choose SELECT TRENDS to place the necessary trends for viewing. You may put any trend on any color. However, it is usually easier if you place them in a logical color format. To select a trend you must click the mouse over the desired data point in the white selection box (after you open the select trends box). After clicking the mouse over the desired data point, you must click on the right-side button of the pen color you wish to assign the data point to. This will "install" that data point on the desired pen color.

3. You should place the following trends up for viewing during the startup:

Reactor Level (Suggested Color - Red).
Deaerator Level (Suggested Color - Light Green).
Hotwell Level (Suggested Color - Dark Green).
Reactor Feed Flow (Suggested Color - Blue).
Reactor Steam Flow (Suggested Color - Magenta).
Neutron Rate (Suggested Color - White).
Neutron Flux (Suggested Color - Light Blue).
Thermal Power (Suggested Color - Dark Gray).
Condenser Vacuum (Suggested Color - Yellow).
Generator Load (Suggested Color - Blue Gray).

The above trends will provide you with data needed during the startup process. After selecting the trends, you can see the trend charts by clicking the mouse over the top of the data trend charts on the control board, or by selecting DISPLAYS and then selecting TRENDS. It is advisable that you leave the trends displayed at all times if possible. Again, this depends somewhat on the screen resolution that you are operating in.

4. Ensure that the condensate storage tanks contain adequate level for a startup. You must remember that these tanks also provide the water for the emergency core cooling system. To check the storage tank levels, click on the WATER TREATMENT PUMPS AND CONDENSATE STORAGE control. Both tanks should be above 50%. If they are not, you must start a makeup system pump by clicking the START button for the pump you wish to start. Remember, makeup water is very expensive. Do not waste it by forgetting to shut the pump off when the tank level is restored. Failure to stop the pump or shut the valve will dump precious condensate down the drain.

5. Ensure that the hotwell level is normal and the hotwell makeup system is in service. You should never attempt a hotwell pump start if you have not verified adequate water in the hotwell. To verify the hotwell makeup status click on the CONDENSER HOTWELL LEVEL CONTROL. The hotwell level setpoint should be set at 0. If it is not in AUTO, click on the AUTO selection. The hotwell level should be near 0. If it is displaying a negative number, it is low and should be filled prior to starting the hotwell pumps.

6. Once you have verified that the hotwell level is normal, you can start a condensate pump and fill the deaerator. To start a condensate pump click on the CONDENSATE SYSTEM control. You should place the DA LEVEL CONTROL in manual by clicking the M key. You should then close the DA FLOW VALVE by clicking on the down arrow key. After the DA FLOW VALVE is closed you can start a CONDENSATE PUMP by clicking the ON button for the desired pump.

7. After sending an outside operator to verify that the condensate pump is running normally, you can place the DA LEVEL CONTROL back into AUTO. This is done by clicking the A key and verifying the red AUTO light illuminates. You should watch the DA LEVEL to ensure that it holds at the 0 indication which is normal level.

8. You must now place a condensate polishing system in service to start the continuous water clean-up process. This is done by selecting the desired polisher and clicking the IN button. The green light should illuminate when the polisher is in service. If there is any question about the status of the out of service polisher, you should start a regeneration. This is expensive, but less expensive than having to shut the plant down due to bad water. To place the out of service polisher into a regeneration, press the REGENERATE button. The red light should illuminate, and the system status display should indicate REGEN.

9. You should now place a condenser circulating water pump in service. This is done by selecting CONDENSER CIRCULATING WATER PUMPS control. All of the valves are automatic on these huge pumps that cool the plant condenser. To start one you must press the ON button for the desired pump. You should verify that the flow increases to more than 500,000 GPM.

10. You should now verify the HEPA filter status. This is done by selecting HEPA FILTER control. The HEPA FILTER should be IN and the BYPASS AIR FLOW should be closed as indicated by the illuminated green CLOSE light.

11. You can now place a reactor feed pump in service. This is done by selecting FEEDWATER PUMPS AND SYSTEM control. You should never place a reactor feed pump in service without first checking the deaerator level. Check your trends or open and check the level by selecting CONDENSATE SYSTEM control. Once the DA level is verified as normal, you can start a reactor feed pump by selecting OPEN on the desired pump's INLET VALVE and CLOSE on the desired pump's DISCHARGE VALVE. After the valves have finished sequencing you can select the ON button for the desired pump. When it has come up to operating speed select OPEN on the discharge valve. This will place the pump on-line.

12. The reactor drum level control should be placed into single element control until the power level on the reactor warrants using the main valve. If the 3 ELEMENT CONTROL LIGHT is illuminated, press the button to turn it off. This will place the control system in single element control. You should also verify that the STARTUP VALVE is the in-service valve. It should be illuminated. If not, click on it. You can place the drum level control in AUTO by selecting the AUTO button. The reactor drum level setpoint should be at 0%. This equates to a normal reactor drum level.

13. You should verify that the emergency core cooling system is ready for operation. This is done by selecting EMERGENCY CORE COOLING SYSTEM and selecting the AUTO button. A yellow light will illuminate to confirm the AUTO selection.

14. You should ensure that the reactor SCRAM control is on. These are the protective circuits that prevent you from destroying the reactor and even yourself in the event of mis-operation. To check the reactor protective circuits you must select REACTOR POWER REGULATION control. The AUTO SCRAM CONTROL is located on the lower left hand side of this control. Press the ON button and verify the red light is illuminated.

15. You can now start the loop - 1 and loop - 2 recirculation pumps. For initial startup only one pump on each loop is required. To start a recirculation pump you must select LOOP -1 (2) RECIRC PUMPS control. The procedure for both loops is the same. You must ensure that you follow this procedure for each loop. You should never place a reactor recirculation pump in service without first checking the reactor

level. Check your trends or open and check the level by selecting FEEDWATER PUMPS AND SYSTEM control. Once the reactor level is verified as normal, you can start a reactor recirculation pump by selecting OPEN on the desired pump's INLET VALVE, and CLOSE on the desired pump's OUTLET VALVE. After the valves have finished sequencing you can select the ON button for the desired pump. When it has come up to operating speed select OPEN on the OUTLET valve. This will place the pump on-line. Remember, you *MUST* start at least one recirc pump on each of the two loops.

16. Now that you have recirculation pumps running and the reactor feed system running, you can stop the off-line core cooling system. This will start the initial steaming process on the reactor due to decay heat. Select the OFF-LINE CORE COOLING SYSTEM control. The best thing to do is leave the inlet valve open and close the discharge valve and stop the pump. To do this, press the left button labelled loop - 1 and loop -2 OUTLET VALVE. This will stop the flow. You can then press the left button labelled PUMP to shutdown the pump. Congratulations! If you have made it this far in the procedure you are now officially warming the system.

17. Select the DEAERATOR STEAM SUPPLY control. Press the AUTO button to place the DA STEAM VLV into an automatic pressure control mode. You should press the UP ARROW key on the PRS SET POINT block to increase the pressure setpoint to approximately 20 psig. The DA VENT VLV should be opened initially to approximately 50%. You must remember that this is venting the air and other non-condensable gasses to the HEPA filter system. The further this vent is opened, the more load that is placed on the HEPA filters.

18. You should now select the MAIN STEAM DUMP CONTROL. This is the large steam valve that bypasses the main steam from the reactor to the condenser. You should press the AUTO button to place it in pressure control mode. You should then apply a 350 (approximately) psig setpoint by pressing the UP and DOWN arrow keys under the SETPOINT title block. This means that the valve will open as necessary to prevent the main steam pressure from exceeding 350 psig.

19. You should now select the REACTOR DRAIN CONTROL. You should place a setpoint of approximately 4” the SETPOINT block. You must click on the setpoint block and then type the desired setpoint. You should then press the AUTO button. This automatically opens the reactor drain valve in the event that the reactor level rises above +4.0".

20. If you are watching your trend charts or other data points, you will notice that you are now heating the system. You should prepare the turbine/generator for rolling at this time. The first step in preparing the turbine generator for rolling is to start the support systems. Select TURBINE SUPPORT SYSTEMS. The first thing to place in service is the LUBE OIL. This is done by pressing the START button. You should dispatch a field operator to check the turbine and oil system for leaks or other problems before moving on. After the lube oil system is operating normally, you should start the HYDRAULIC OIL SYSTEM. Press the START button for the HYDRAULIC OIL system. You should now open the STEAM DRAINS for the turbine. Press the OPEN button for the steam drains. Do *NOT* start the steam seal system at this time. It should not be started until after the turbine is placed on turning gear in the next step.

21. Select TURBINE CONTROL. You should press the TURNING GEAR ON button. If it starts, the RPM will increase to approximately 20 RPM and the TURNING GEAR indicator will illuminate red.

22. Return to the TURBINE SUPPORT SYSTEMS and press the STEAM SEAL START pushbutton. The START light should illuminate red and the pressure should increase to more than 5 psig if there is steam pressure available.

23. You can now start the vacuum system. Select CONDENSER VACUUM SYSTEM. Press the CLOSE button on the CONDENSER VACUUM BREAKER. This is the valve that opens to release the condenser vacuum when you shutdown. Press the CONDENSER VACUUM PUMP button to ON. NOTE: Until sufficient steam pressure is available on the main steam line the vacuum system will not operate and the ON light will not illuminate. You must have at least 250 psig main steam pressure to have enough motive steam for the air ejectors to function correctly. Also, you should never start the condenser vacuum system until the turbine is on turning gear and the steam seals are on.

24. You should allow decay heat to increase the steam pressure until 350 psig is reached. When you reach 350 psig the steam dump control valve should open to maintain this pressure. When the condenser vacuum increases to maximum the turbine can be reset. Select the TURBINE CONTROL and press the RESET button. If the permissives are met the turbine will reset and the SPEED SETPOINT selection indicator will illuminate at 900 rpm. The turbine will not roll until it is selected to AUTO or until you manually increase the valve position. However, you do not presently have sufficient energy in the steam to safely roll the turbine.

25. Select REACTOR POWER REGULATION control. Under the AUTOMATIC REACTOR CONTROL heading you should press the ON button. This allows the automatic reactor control to take over once you do a rod pull and bring the reactor to critical. Using the UP ARROWS on the POWER SETPOINT block, increase the power level setpoint to 5%. The left arrow increases the power level setpoint 5% at a time, and the right arrow increases the power level at .5% at a time. These settings do not affect the reactor until after you manually pull to critical with the absorber rods. You should also press the RESET button on the REACTOR SCRAM portion of the regulator panel. If all of the permissives are met the reactor control rods should reset at this time.

26. At this time you can start a rod pull to begin a chain reaction and bring the reactor to critical. Select the ABSORBER ROD CONTROL. Press the CENTER CORE ONLY button. It should illuminate red. This pulls only the absorber rods in the center of the core. This keeps the outer core rods inserted for safety purposes during the initial rod pull. You should now select the S (slow) M (medium) or F (fast) pulling rate. The ideal method is to select F until the negative log flux indicator approaches a positive (+) setting. The negative log flux indicator is the data field below the PULL RODS button. This is your best indication of when the chain Reaction will start. Remember, the neutron rate will increase exponentially when you go critical. Press the F button to do a fast pull, and the press the PULL RODS button. The rod position indicators for the central rods should begin changing. The indicators show the percent inserted. When they read 100%, this indicates the absorber rods are 100% in the core.

27. Select SCHEMATICS on the pull down menus. Select the REACTOR CORE STATUS schematic. This schematic should be viewable during the initial pull to critical stage. You should also be monitoring the trend charts for neutron rate, neutron flux, and thermal power.

28. When the negative log flux reaches approximately -4.00, you should press the S button to change the rod pull rate to SLOW. At this time, you should monitor the trend charts very carefully and watch the maximum fuel temperature. The maximum fuel temperature is indicated on both the absorber rod matrix and on the CORE STATUS schematic. The two highest fuel channels will always be indicated in red.

29. Once you have gone critical, the reactor should maintain the power level that you selected earlier. Select REACTOR POWER REGULATION control. Using the UP ARROWS on the POWER SETPOINT block, increase the power level setpoint to 10%.

30. As you increase your power level, the steam dump valve to the condenser will open to maintain the pressure setpoint you placed in earlier. You should now increase the pressure setpoint to 650 psig in preparation for turbine roll. To increase the pressure setpoint on the steam bypass valve select the MAIN STEAM DUMP CONTROL. You should then apply a 650 (approximately) psig setpoint by pressing the UP and DOWN arrow Keys under the SETPOINT title block. This means that the valve will open as necessary to prevent the main steam pressure from exceeding 650 psig.

NOTE: When the main steam pressure reaches 650 psig, you may now start the turbine roll. This can be accomplished in MANUAL by opening the steam bypass (startup) valve while monitoring the turbine speed, or automatically by placing the turbine speed control in AUTO. The recommended method to roll the turbine is AUTO. This is because anytime you have a very large rapidly rotating mechanical device with minimal clearances between the parts, you have the potential for serious damage if something rubs.

Since we have already covered that a steam turbine is a heat device and not a pressure device we must be careful to limit the rate and the amount of temperature change within the turbine during operation. Since the rotating portion of the steam turbine is not connected to the stationary portion, rapid changes in steam temperature can cause the rotating portion to expand or contract quicker than the stationary portion. This can cause severe problems in a steam turbine if this growth Is not controlled. We call this expansion and contraction *differential expansion*.

The differential expansion meter on the Chernobyl turbine is indicated on the turbine controls section next to the vibration meter. If you change steam temperature too fast the turbine rotor tends to thermally expand or contract quicker than the heavier shell section of turbine. This is noticed during the roll-up or large changes in the turbine power output. As the steam flow through the turbine is increased or decreased, the temperature within the turbine changes. This temperature change almost always affects the turbine rotor first. As a general rule, try and limit how fast you increase the turbine speed during roll-up. Too fast, or too much of a change all at once will cause high differential expansion in the turbine. This differential expansion, if severe, will trip the turbine and if too severe, cause extensive damage to the rotating and stationary portions of the turbine.

31. With all this said, you can now place the turbine into AUTO by selecting TURBINE CONTROL and pressing the AUTO button. It should illuminate and the MANUAL indicator should go out. When you press the AUTO button, the turbine startup valve should start ramping open. The SPEED SETPOINT should be pre-selected to 900 rpm and the roll rate should be SLOW if the turbine has been off-line for more than 48 hours. The roll rate should be MEDIUM if the turbine has been off-line less than 48 hours, but more than 24 hours. The roll rate should be FAST if the turbine has been off line less than 24 hours.

32. When the turbine reaches the first AUTO stopping point (900 rpm) you should view the vibration and the differential expansion. If they are very low, press the next speed stopping point button (1800 rpm). Continuously monitor the reactor and other parts of the plant to ensure everything is working properly.

33. When the turbine reaches the second AUTO stopping point (1800 rpm) you should view the vibration and the differential expansion. If they are very low, press the next speed stopping point button (2700 rpm). Continuously monitor the reactor and other parts of the plant to ensure everything is working properly.

34. When the turbine reaches the third AUTO stopping point (2700 rpm) you should view the vibration and the differential expansion. If they are very low, press the final speed stopping point button (3600 rpm). Continuously monitor the reactor and other parts of the plant to ensure everything is working properly.

35. When the turbine reaches 3600 rpm you should check and see how far open the MAIN STEAM DUMP CONTROL valve to the condenser is. It should be nearing closed. It will be necessary to increase the setpoint to above 1600 psig. This will close the bypass valve and allow the turbine to control the reactor steam pressure by adjusting the turbine inlet valves. To increase the setpoint on the main steam dump control valve you must select the MAIN STEAM DUMP CONTROL You should then apply a 1650 (approximately) psig setpoint by pressing the UP and DOWN arrow keys under the SETPOINT title block.

36. At 3600 rpm on the turbine you should select the generator synchroscope to the ON position. This is done by pressing the SCOPE ON/OFF button. Once pressed, the scope should be begin rotating. If the turbine is left in AUTO, the scope will eventually steady out at about 6 rpm in the fast (clockwise) direction. When the scope reaches just a few degrees before top dead center (TDC), press the CLOSE button on the generator circuit breaker. If the scope is slow enough and the angle of closure was correct, the generator circuit breaker will close.

37. You should notice that when the generator circuit breaker closed the turbine throttle pressure at the time of closure became the pressure setpoint. From this point, changes in power on the reactor will cause the pressure in the system to change. These pressure changes will cause the turbine valves to change as Necessary to maintain the pressure setpoint. The generator power (megawatts, located in the lower left-hand corner of the turbine control panel) will increase and decrease proportionally.

Remember, energy in = energy out.

38. You can now increase the reactor power level to 15%. This is done by selecting REACTOR POWER REGULATION control. Using the UP ARROWS on the POWER SETPOINT block, increase the power level setpoint to 15%.

39. At approximately 80 or more megawatts there are several items that should be done. These items are:

- Select the FEEDWATER PUMPS AND SYSTEM control and change to three (3) element control, and place the MAIN VALVE in service. This is done by pressing the MAIN VALVE button. The STARTUP VALVE light should go out, and the MAIN VALVE LIGHT should illuminate. You should also press the 3 ELEMENT CONTROL BUTTON. It should illuminate.
- Select the TURBINE CONTROL and place the MAIN VALVE in service by pressing the MAIN VALVE button. The red light on MAIN VALVE should illuminate, and the red light on STARTUP should go out.
- Select the TURBINE SUPPORT SYSTEMS control and close the turbine drains. This is done by pressing the CLOSE button on the STEAM DRAINS.

40. You can now increase the reactor power level to 20%. This is done by selecting REACTOR POWER REGULATION control. Using the UP ARROWS on the POWER SETPOINT block, increase the power level setpoint to 20%.

41. At this time you can place a second condensate pump in service. This is done by selecting CONDENSATE SYSTEM and pressing the ON button for the second CONDENSATE PUMP.

42. At this time you can place a second reactor feed pump in service. This is done by selecting FEEDWATER PUMPS AND SYSTEM and then selecting OPEN on the desired pump's INLET VALVE, and CLOSE on the desired pump's DISCHARGE VALVE. After the valves have finished sequencing you can select the ON button for the desired pump. When it has come up to operating speed, select OPEN on the discharge valve. This will place the pump on-line.

43. At this time, providing the vibration and differential expansion are normal on the turbine, you can increase the reactor power level to 25%. This is done by selecting REACTOR POWER REGULATION control. Using the UP ARROWS on the POWER SETPOINT block, increase the power level setpoint to 25%. You can also place the THERMAL POWER CORRECTION system in service by pressing the ON button. This provides compensation for the reactor control system.

44. From this point on the reactor power can be increased slowly to 100%. During this time you will have to monitor and perform the following functions:

45. Begin increasing the pressure setpoint on the turbine valves to 1500 psig. This is done by selecting TURBINE CONTROL and clicking on the PRESSURE SETPOINT block and then typing in the desired setpoint. The setpoint should be increased slowly, changing no more than 50 psig each change cycle.

46. At approximately 250 megawatts you should place a second reactor circulation pump in service. This is done by selecting LOOP -1 (2) RECIRC PUMPS control. The procedure for both loops is the same. You must ensure that you follow this procedure for each loop. You should never place a reactor recirculation pump in service without first checking the reactor level. Check your trends, or open and Check the level by selecting FEEDWATER PUMPS AND SYSTEM control. Once the reactor level is verified as normal, you can start a reactor recirculation pump by selecting OPEN on the desired pump's INLET VALVE, and CLOSE on the desired pump's OUTLET VALVE. After the valves have finished sequencing you can select the ON button for the desired pump. When it has come up to operating speed, select OPEN on the OUTLET valve. This will place the pump on-line. Remember, you MUST start at least one recirc pump on each of the two loops.

47. At approximately S00 megawatts you should place the second circulating water pump in service. This is done by selecting CONDENSER CIRCULATING WATER PUMPS. All of the valves are automatic on these huge pumps that cool the plant condenser. To start one, you must press the ON button for the desired pump. You should verify that the flow increases to more than 1,000,000 GPM.

48. This concludes the startup procedure. Congratulations, you are now making money.

12.0

User Tips, Secrets, and Other Useful Information

The Chernobyl software program has some advanced functions that can enhance a power user's experience. Exploring the program will reveal many of these items. If exploring is not your way, then read this section for some quick tips. These tips are listed in the order of importance to many of our beta testers.

MALFUNCTION CONTROL - Many of the beta testers felt that a chance to operate the plant without malfunctions would make the simulation more enjoyable and allow them time to learn the operation without constantly fighting breakdowns and failures. For this reason we have placed a malfunction toggle that allows you to turn
malfunctions off and on. This toggle is located at the bottom menu bar on the DAY and TIME menu function. Click on the DAY and TIME menu function located on the bottom of the page. This will open a box labelled OPTIONS. This box contains information about the simulation that include:

- The model update time in seconds.
- The free memory.
- The free system resources.
- The status of random failures (malfunctions).

On machines low on memory or whose system resources are less than 70% it may necessary to slow the update time down. To do this you must click on the OPTIONS heading. This will open a box that is labelled:

- Units
- Time Step
- Malfunctions

If you click on the UNITS menu item, a choice box will appear that allows you to change between metric and American units. This allows user's to choose which measurement system the simulator operates with.

If you click on TIME STEP a choice box will appear that allows you to change the update time steps. The choices are 100ms (default) and 200ms. If your machine is a slower Pentium or 80486 or if you are operating with less than 16 Mb of RAM, the program may function better if you choose the 200ms setting. This halves the number of calculation cycles and allows slower processors to "keep up" with the program. If you are unsure if you need to slow the update cycles, try the 200ms setting. If the program appears to operate better or if random processor "locking" (the processor quits responding requiring a re-boot) stops, then leave the 200ms setting on.

If you click on MALFUNCTIONS a choice box opens that has two choices. They are ON and OFF. If you choose the OFF setting, all random failures will be averted. This setting allows you to operate the Chernobyl simulator without malfunctions.

DIAGNOSTIC MODE - For advanced user's there is a diagnostic mode. This mode is initiated by placing a command line prompt of /D in the startup file. To place the program in diagnostic mode click once on the Chernobyl icon that starts the program. Do not start the program, you should only highlight the icon. When it is highlighted click on the right mouse key once. This opens a dialogue box that allows you to do many functions. On the bottom of this dialogue box there is a setting for PROPERTIES. Clicking on this item opens a second box that has two choices. The first is General and the second is *Shortcut*. If you click on SHORTCUT there is a data field that is libelled TARGET. On this line is the path and executable call that starts Chernobyl. Directly after the CHERNOBYL.EXE you must place a space and a /d. After adding this to the command line, you must APPLY it on the bottom of the screen. The next time you bring the simulator up it will be in the diagnostic mode.

Diagnostic mode places another prompt under the pull down menu called DISPLAYS. This prompt is, appropriately enough, called DIAGNOSTICS. When you click on the diagnostics prompt a menu item box opens that looks like figure - 33.

This display box allows you to select a fuel channel leak and repair using the rows and columns in the upper left-hand corner.

This box also allows you to play movies and select specific malfunctions by the number.

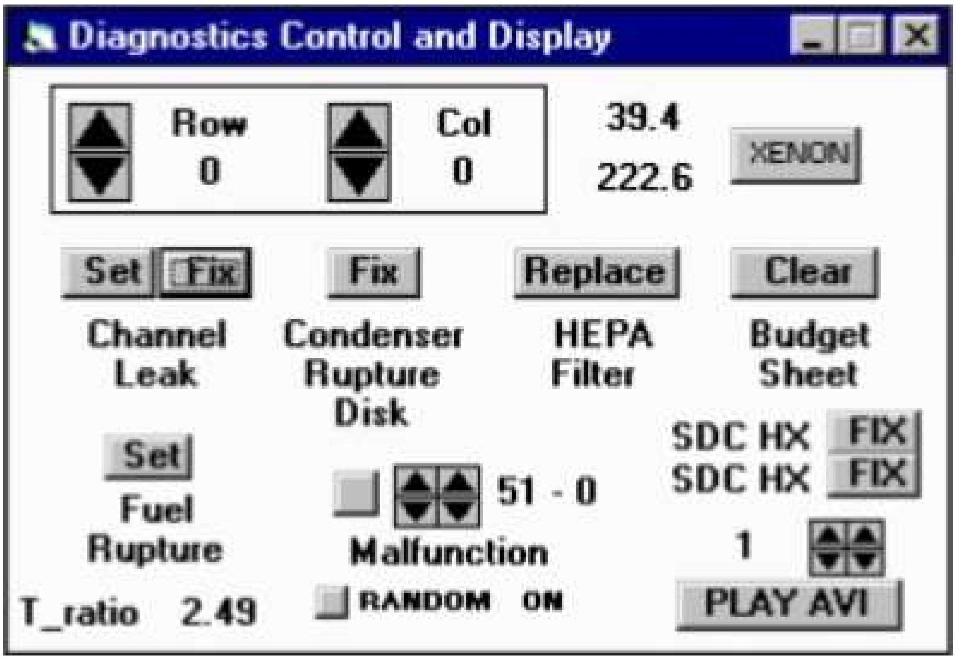


Figure 33: Diagnostic Controls

Experiment with the diagnostic screen, there are some powerful tools available.

entertain
educate
simulate
demonstrate

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