How the Thorium Reactor and Steam Generator Work

First, print this article out so you can refer to it while looking at a steam plant drawing. It's probably best to look at the middle drawing on the opening page - the one about a coal power plant. Click on the drawing a couple of times to enlarge it enough so that you can read the small lettering. There are two new modules: the reactor barge and the steam generator module (which replaces the boiler).

There is no boiler in this system. The original coal burning boiler has been replaced with a set of steam generator heat exchangers that emulates a typical coal power plant's Loeffler boiler. I got this boiler emulator idea from both ORNL EBASCO and Rosatom BN-600 drawings so I can't claim it on a patent. Further, this system is incapable of producing a boiler explosion.

The THORIUM REACTOR. The reactor is basically a tank filled with graphite (what we call "pencil lead"). The graphite is cut to fill the tank tightly leaving a space at both the top and bottom. Dozens of tubes spaced about 2 inches apart - arranged in a grid - are drilled the length of the graphite between the top and bottom spaces to allow the molten fuel salt to flow through the graphite from bottom to top.

Somewhat like slowing a passing meteorite to assure that Earth's gravity will draw the meteorite to crash into it, the graphite slows neutrons – moderates their speed - thereby increasing the chances the neutrons will crash into nearby uranium atoms and cause the atom to break apart - or fission – releasing a bit of heat in the process.

There are no tubes drilled near the edges of the graphite. This thick graphite edge keeps neutrons in, acting as the first of three radiation containment shields in the reactor barge concept. The other two containment shields are the 3 foot thick concrete and steel walls of the reactor's 70 feet in diameter, 50 foot high containment cell (colored blue) and the three foot thick concrete walls of the concrete reactor barge (colored gray).

The molten fuel salt has dissolved radioactive fuel (usually uranium-235) in it which is radiating neutrons that fission (split) adjacent atoms which, in turn, produce the reactor's heat as the salt travels up through the reactor tank from bottom to top via the tubes drilled in the black graphite block in the reactor tank.

Once the reactor is up and running on something radioactive, non-radioactive thorium can be blended into the liquid fuel. Thorium, when exposed to radioactivity, changes over about a month into radioactive uranium-233 and becomes the reactor's fuel. The reactor can be kept running for about 30 years on thorium before the fuel salt becomes so contaminated with fissioned uranium-233 it will stop running.

At 30 years, the salt is cleaned by precipitation and the graphite rods, swollen by 30 years of exposure to intense radiation are replaced with fresh graphite rods.

Pumps next to the top of the reactor tank then pump the heated fuel salt down through the 4 primary heat exchangers inside the reactor cell which then heat the non-radioactive "clear salt" loop.

Notice the molten salt travels through the heat exchangers so fast the salt's temperatures don't change much more than 100F.

The STEAM GENERATOR. The clear salt (salt loop 2) then leaves the reactor barge and is pumped to the salt-to-salt secondary heat exchanger where it then heats the tertiary salt loop - salt loop 3 (a commercial salt of a different type called "HITEC") which both takes care of a tritium problem and carries the heat to the steam generator module (right-hand room of the "New Steam Generator"). These things are big - the evaporator-superheaters on the BN-600 are over 40 feet high.

The following steam pressures and temperatures are generic values right out of the "Steam Plant Operation" handbook by Woodruff, Lammers, and Lammers.

Any actual steam configuration in turbine size, steam temperature, or steam pressures, from superheated to ultra-supercritical can be emulated using these inexpensive "Shell and Tube" steam generators. No changes to the turbine or water treatment equipment should be necessary. If desired, steam selector valves can be installed at the turbine to create a "Dual-Fuel" - i.e., coal or nuclear - power plant. It should work just fine on either steam source.

One neat thing is that the steam generation control valves should enable a "Fine Tuning" of the steam quality to a level not attainable by the damper panels in Loeffler boilers. The valves are set up to never close completely during normal operation and there is an end of loop heat exchanger by-pass salt line to assure the salt lines never get cool enough to go solid. The pipe lines and valve bodies are traced (wrapped) with nichrome heating wire (like in your toaster) in the unlikely event solidification ever does happen.

Water expands 1,600 times in volume when it changes from water to steam. If not allowed to expand, its vapor pressure will rise dramatically. A wonderful way to turn thermal energy into mechanical energy for 300 years.

The steam generator module does 4 things.

1. It preheats the condensate water (blue water pipe line) to 500F so that thermal shock will not crack or overload the evaporator. This temperature also sets the lowest [saturated] steam pressure available.

2. The evaporator temperature sets the operating (saturated) steam pressure. When running at 670F the evaporator sets the steam pressure to 2,500 psig. The diagonal vanes in the evaporator spin the steam to centrifuge out any microdroplets.

3. The steam then rises through the superheater section where the steam is superheated from 670F to 1,000F (red steam line). (Superheating means the steam is hotter than is necessary for its pressure. This makes steam more powerful and also “dry”, like a gas.) The steam then passes through the high pressure stage of the turbine where it expands, dropping the pressure to 550 psig and the temperature to 500F (pink steam line). (If running at part power, the HP turbine can be by-passed.) This temperature/pressure combination takes the steam dangerously close to becoming wet fog (477F @ 550 psig), which will rapidly destroy by erosion the blades and buckets of the intermediate stage (IP) turbine.

4. To make the steam safe for use in the intermediate turbine, the steam is reheated from 500F to 1,000F to dry it out and then the steam is run through the intermediate pressure turbine. The pressure remains at 550 psig.

The steam then leaves the intermediate pressure turbine stage and immediately goes to the low pressure or "condensing" stage turbine at 710F and 170 psig and then on into the steam condenser (hot well) which is running at a slight vacuum to keep the steam from forming fog. At this point the steam flashes back into water – reducing its volume 1,600 times and thus maintaining the vacuum – and the water is then run through a de-aerator and then into a storage tank for the next trip around. That's it!

COMMENTS:

Even with the additional cost of a concrete barge, and considering the fact everything metal that touches molten salt has to be made of even more expensive nuclear and corrosion resisting Hastelloy-N instead of already costly stainless steel, the thin unpressurized reactor tank and the thin unpressurized "Shell and Tube" heat exchangers are relatively dirt-cheap when compared with the heavy 10 inch thick stainless forgings needed to restrain the enormous supercritical water pressures (Supercritical water - under so much pressure it can't turn into steam) found in your local solid-fuel reactor.

RG Donnelly's book has important information about heat exchanger welding and brazing.

Since conventional reactors run about 550F, they are not able to produce the more efficient 1,000F steam temperatures coal produces. Molten salt reactors, however, were running at 1,300F right from the beginning.

The reactor containment cell can be buried in an underground silo for additional radiation shielding if the barge is not an option. Air cooled, this reactor cell won't make any additional demands for cooling water.

Making the reactor barge a stand-apart module with molten salt feed and return lines to a reactor is not to be found in the literature. This enables quick disconnect from the steam generator module for quick barge replacement. Using the secondary heat exchanger as a load-consolidating heat distribution device (see Big Bend and Jorf Lasfar) is also undocumented as far as I know but the idea of having one boiler drive many different heat zones (such as in steam heating) is as old as the hills.

The combination of unpressurized molten salt and 2,500 psig superheated steam in the same heat exchanger is a marriage made in hell. If you run it long enough - many decades - eventually one of the many pipe welds in the top of the superheater will rupture (a highest temperature, pressure, and vibration point), forcing the tertiary salt loop to high pressure, threatening the secondary loop and possibly the radioactive primary fuel salt loop in the reactor itself. That's why there are five overpressure rupture discs in the system. This part of the steam generator building should never be routinely occupied. It will be god-awful hot in there anyway.

The inerting gas cascade is set up to detect and handle fine leaks between salt stages, forcing any leakage toward the reactor and its confinement cell.