4. REALITY

As previously stated, the *Simplified Rankine Cycle* and System that was developed and analyzed represented *ideal* conditions, with everything associated with it, whether identified or not, similarly being 100% perfect and 100% efficient. However, this is <u>not</u> reality, and as in most other disciplines, Engineering included, reality is rarely if ever *ideal* or 100% efficient. When reality *is* incorporated into our System and analysis, matters quickly become very 'complex' (for a lack of a better term). In our example, this 'complexity' means several things, some of which may not be obvious at first glance. First, each step of our *Simplified Rankine Cycle* employed a singular component to represent each of the four legs of the *Cycle's* Process. This, in our Nuclear Power Plant example, is not accurate, as there are literally thousands upon thousands of ancillary components contained within, but not shown, in the four Process legs. Additionally, each Nuclear Plant includes the replication of *identically functioning systems* to absolutely assure operational continuity, safety and System efficiency [10].

In a typical 1.2 Gigawatt Nuclear Power Plant, there are not one but three Reactor Feed Pumps delivering liquid to the Reactor. Each Feed Pump is driven by its own dedicated 8600 HP, 5100 RPM, six-stage steam Turbine. There are actually four Main Turbines, not just one, and of these four, one is a High Pressure (HP) Turbine, while the remaining three are Low Pressure (LP) units. The Turbines are connected in tandem to each other and the Main Generator and Alterex (which supplies excitation to the Generator field coils and also rectifies the Generator's output). The entire Turbine-Generator-Alterex 'train' is approximately 120 yards long. In operation, all of the Reactor's steam is delivered to the first HP Turbine, and upon discharge it is divided into six equal flow streams with two equivalent streams directed to each LP Turbine. Each LP Turbine discharges into its own dedicated hermetic Condenser; each Condenser is approximately 70 feet tall and has a volume equivalent to that of a single family home. To extract the residual heat in the LP Turbines' exhausts, approximately 30,000 heat exchanger tubes are incorporated in two banks of 5,000 tubes per Condenser, these tubes circulate the cooling water to and from a single 540 foot tall Cooling Tower. A single Cooling Water Pump circulates the cooling water to and from the Condensers and Cooling Tower. Finally, the flow of each of the four Process paths includes and inordinate amount of <u>very</u> necessary intermediate support systems comprised of mechanical, electrical, and

[10] With the exception of the largest components, such as the Reactor, Main Turbine-Generator, Condensers, etc., <u>every system and component</u> is replicated by equivalent identical and fully functional A and B operating systems, such that if <u>any</u> A System 'goes down' for any reason, an <u>identical</u> B System can be immediately energized (many times automatically) and the Plant will continue to function without any interruption.

instrumentation equipment. Many of these systems and components are, by necessity, safety related. All of this ancillary equipment is not identified on our previous diagrams.

As a reader unfamiliar with Nuclear Plant design and construction, one might ask what *specifically* the previously stated 'intermediate equipment' is and for and what purpose it serves. One fundamental example of such need follows. First, it is common knowledge that any high speed steam Turbine cannot withstand any liquid impingement upon its blades – the Process System must supply a gas as the motive fluid, otherwise the kinetic energy of even a small amount of liquid striking a fast-moving blade quickly results in blade erosion, excessive strain, even catastrophic failure. If one returns to Figure 6, one will note that the Process between Points #3 to #4 travels straight downward, because this path is *defined* as being 100% efficient (meaning that the change in Entropy is zero and the line must be vertical and straight). However, this condition as rendered cannot be tolerated by the equipment. As the fluid is depleted in energy, more and more of it changes state into a liquid. This is evident by viewing the curved lines within the Vapor Dome entitled *Constant Quality*. *Quality* is defined as the quantity of the fluid mass that exists as a gas and only a gas. One hundred percent *Quality* means that the fluid is entirely steam, 90% *Quality* means that 10% is liquid water and 90% is steam, and so forth. As is evident in Figure 6, even at a relatively high temperature of 400° F, the *Quality* of the flow stream is approximately 85%, meaning that 15% of the entire quantity of fluid within the Turbine itself is a liquid. This condition is patently unacceptable and extremely dangerous!

Realty once again rears its head. The design Engineers realized this and came up with a brilliant solution, which as previously alluded to, is to direct the Reactor's entire flow to the initial HP Turbine. In this first Turbine, the steam will lose Enthalpy and some will condense into a liquid. The resultant exhaust stream will have entrained micro-spheres of liquid water enveloped by the remaining steam. The Engineers designed into this exhaust stream not one but two large Moisture Separators that are able to extract the liquid, but leave the remaining steam available for the other LP Turbines. Further, the liquid from the two Moisture Separators is not directed into the Condensers, where its residual heat will be 'thrown away' into the atmosphere, but rather it is directed to several Feedwater Heaters, that preheat the fluid entering the Reactor well beyond the theoretical 95º F identified in Figure 6. In fact, *if* 95º F water *were* to be injected into the Reactor, its fuel bundles would literally shatter due to thermal shock, as their temperature exceeds 1500º F. So, removing the HP Turbine's exhaust stream's liquid and using it to preheat the Reactor's inlet fluid is both intelligent and thermally efficient as it solves three issues – (1) it saves stress and the potential for downstream LP Turbine blade destruction due to liquid impingement, (2) it preheats the fluid entering the Reactor precluding fuel bundle destruction, and (3) it improves the Cycle's overall thermal efficiency by not discharging the liquid's latent heat into the atmosphere, but instead recycling this heat back into the Process. Smart, very, very smart!

This Section could be expanded to include many more examples of the differences between a Power Plant based upon a *Simplified Rankine Cycle* and one that exists based upon 'real life' practical necessities. The differences are striking, and to exemplify only but a portion of these differences, including the addition of a Moisture Separator *and* Cycle Reheat, Figure 7 is provided. Figure 7 illustrates an actual *Reheat Rankine Cycle* PFD which is annotated with the equivalent four leg starting & ending PFD Points of the non-reheat *Simplified Rankine Cycle* as identified in Figure 5.

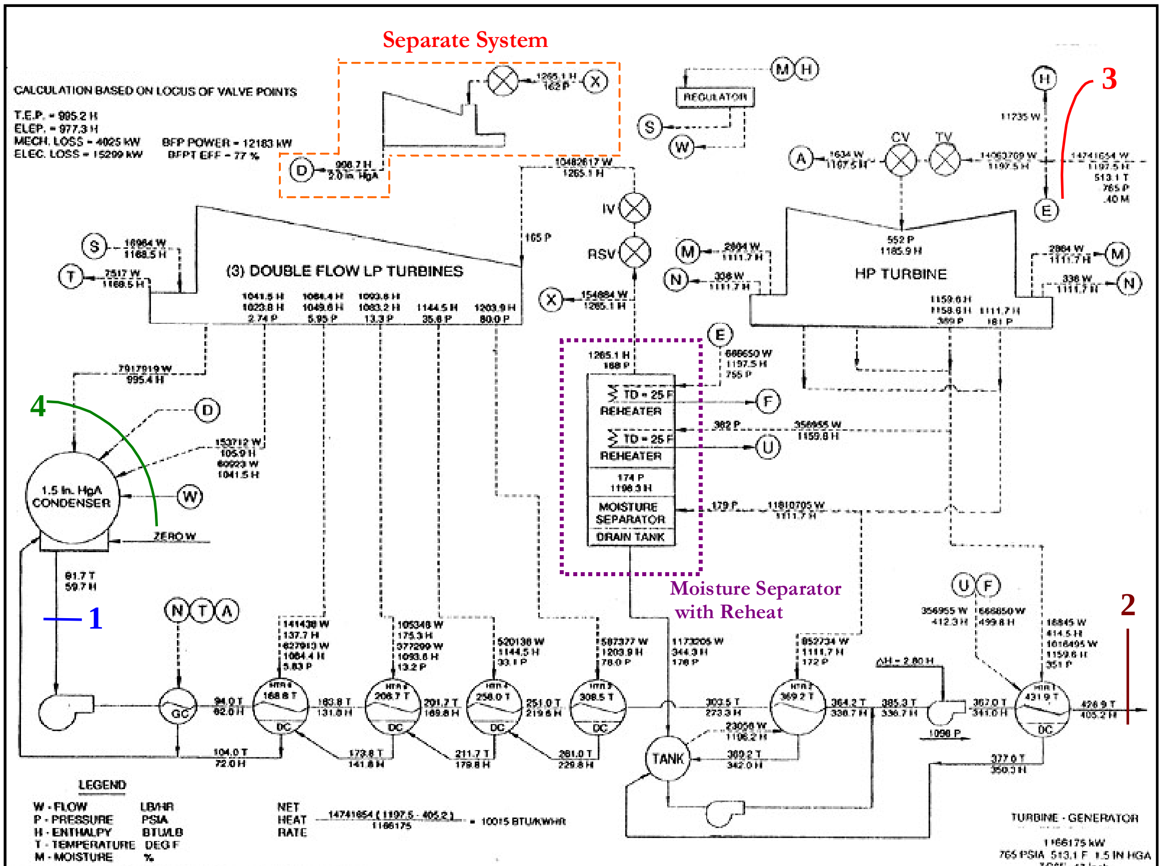

Figure 7 Reheat Rankine Cycle Process Flow Diagram

The reader may find it of interest to have additional information about the Nuclear Plant illustrated in Figure 7, specifically that of answering several pertinent questions. The first of these may likely be to ask what quantity of mass flow of water is required of the System's process to generate a phenomenal 1.2 GW of power from one facility? The far right hand portion of Figure 7, just to the right of Point #3 provides the answer – 14,741,654 LbM/Hr! The second question of interest is what is the thermal efficiency of the Process as depicted? The answer is 34.1%. The final question that begs an answer is what is the quantity of heat that must be generated by the Reactor in order to yield 1.2 GW of useful power if the entire Process is 34.1% thermally efficient? The answer is 3.423 GW, or (ready?) 11,681,672,100 BTU/hr!

One final figure is provided, Figure 8, it being a collage of several images of an *actual* existing two-unit BWR Nuclear Power Plant, and three of the key components that were previously illustrated (in icon form) within the *Simplified* Rankine Cycle Process Flow Diagram. Of particular note is the immense size of such a plant, as well as that of the three components located within each unit – the BWR Reactor, the compound-tandem Main Turbine Generator-Alterex, and the Reactor Feed Pump. Numerous site structures are identified; the figure includes a listing of these structures by identity and location [11]. Lastly, to aid the reader in identifying where each component 'fits into' the Rankine Process Diagram, the previous *Simplified* Rankine Cycle PFD is included as a guide.

In closing, it bears some deep consideration that the existence of every modern day Nuclear Power Plant, inclusive of all of its many Systems and sub-Systems, would *not* have been possible without some individual possessing complete fluency in Thermodynamics. Possessing these skills, then applying Thermodynamics' many Laws, principles and teachings, he would have completed the *Simplified* Rankine Cycle PFD and made the associated calculations that are illustrated in this paper, subsequently concluding that such a Plant, in principle, was technically feasible and achievable. Everything thereafter, including *all* of the Engineering and the actual construction of the Plant, was as a result of this initial analysis. Quite literally, <u>nothing</u> would have been possible without Thermodynamics or without those savants who spent their entire careers, and lives, in its study so that Humanity could benefit from the machines that Thermodynamics makes possible.

[11] The reader may question where site workers are. They are there, you just cannot see them. At the scale of the photo provided, a 5 ft.-10 in. tall individual would be approximately .0125 in. tall in the image!