Using PEPSE® To Analyze Feedwater Heaters With Long Drain Coolers

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Commonwealth Edison Company is an investor owned utility based in Chicago, Illinois. We service approximately 3 million customers in Northern Illinois with about 24,000 MW's of available capacity. This capacity includes power from 12 nuclear units, 24 fossil units and 69 fast start peaking units.

We have been in the process of modifying our fossil units for increased cycling and have been replacing high pressure feedwater heaters that are over 10% plugged. The PEPSE feedwater heater design mode is used extensively to evaluate vendor bids on new feedwater heaters. We feel that we need some way to verify the terminal temperature difference (TTD) and drain cooler approach (DCA) that the feedwater heater vendor guarantees when the bids are evaluated. To hold the vendor to the guaranteed TTD and DCA would be very difficult, even if a certified ASME acceptance test were run at the station upon completion of installation. If the results of the test showed poor performance, it would be too late to take any corrective action on the heater in question because it had already been installed.

PEPSE allows us to compare all the heater manufacturers designs relative to one another. This allows us to make a more informed decision as to which heater to purchase. Although there were some approximations made in our modeling of the heaters, we feel that our long drain cooler model configuration gives very accurate results. They have been verified with heater acceptance tests following installation.

In a long or split pass drain cooler heater design (Attachment 1) the drain cooler runs the full length of the heater. This design does not have the entire tube bundle passing through the drain cooler. Consequently, not all the feedwater goes through the drain cooler. Instead a portion directly enters the condensing zone. Thus there are two separate streams at different temperatures mixing at the feedwater outlet nozzle box. The advantages of a heater with a split pass drain cooler are as follows:

1. The long drain cooler design has a drain cooler that is always submerged in liquid. It utilizes the normal liquid level in the heater for subcooling, whereas the conventional design drain cooler cuts across the full tube bundle (Attachment 1). It is taller in height, but shorter in length. The conventional design uses separation plates and pressure difference to increase the cooler liquid level height. This may not work well at lower turbine loads when extraction pressures are reduced. Thus, the shell pressure may not be sufficient to drive the steam condensate out of the heater. Water and steam mixtures may enter the heater shell drainage line (Attachment 2), eventually causing erosion of the drain cooler tubes near the end plate. This problem is not seen in the long drain cooler.

2. The long drain cooler design is not subject to the reheat effect in the subcooling zone. The top shroud of the drain cooler does not directly border the desuperheating zone (Attachment 3). The reheating effect occurs when the warmer surface of the top desuperheating zone separation plate heats the liquid in the drain cooler. (Attachment 4).

3. There is much better water level control in the heater. This allows the heater to operate consistently at its optimal TTD and DCA.

The long drain cooler disadvantages are:

1. More tubes are required over the standard design (Attachment 3). In the case of one 350 MW dual string unit, approximately 80 more tubes were required. Not all the feedwater goes through the drain cooler so more heat transfer area must be included to achieve the same (TTD). This also could make the heater much longer thereby requiring additional structural supports. These factors raise the cost of the heater 5 to 8% over a heater with a short drain cooler.

2 The additional weight of the heater requires verification of load carrying capability of the supporting plant structure.

3. The possibility of steam side condensation in the desuperheating zone outlet. This will be discussed later in detail.

A model that would readily simulate the long drain cooler design model is shown in Attachment 5. Note that it is actually constructed with two heater design models. This was necessary because PEPSE's feedwater heater has all of the tubes passing thru the drain cooler. In other words, PEPSE assumes a short drain cooler. A type 19 (a two zone heater without a drain cooler) and a type 18 heater (a three zone heater with a drain cooler) were used to make the model. The type 18 and 19 heaters were then mixed together to form one feedwater heater with a desuperheating zone and a long drain cooler. Except for duplication of the heaters and need for extra mixers and splitters, the model is the same as the standard PEPSE design mode submodel. The following assumptions were made with this model:

1. The feedwater flow rate was proportioned by: the number of tubes in the drain cooler section over the total tubes in the tube bundle. This could be done because all the tubes in the bundle were the same size, had approximately the same pressure drop and flow through each tube. (Attachment 6)

2. The heat transfer area in the desuperheating zone was split between the two heaters by the same portion discussed above.

3. The heat transfer area in the condensing zone was split between the type 18 heater with a short drain cooler and the type 19 heater without a drain cooler as follows:

   a. Since the number of tubes in the drain cooling section (N_{18}), the drain cooler heat transfer area ($A_{DC\ 18}$), and the number of remaining tubes (N_{19}) are known; then the additional condensing area (A'_{C19}) in the type 19 heater can be calculated. Because the lower condensing area (A'_{C19} in Attachment 6) is the same length as the drain cooler we can use the following proportion:

$$\frac{\text{Surface Area}}{\text{Tubes}} = \frac{A_{DC18}}{N_{18}} = \frac{A'_{C19}}{N_{19}}$$

$$\text{Therefore: } A'_{C19} = \frac{N_{T19}}{N_{T18}} \times A_{DC18}$$

   b. Next the above area (A'_{C19}) is subtracted from total condensing area available (A_{CTOT}) to give the remaining available area.

$$A_{CTOT} - A'_{C19} = A_R$$

c. The remaining area is then proportioned between the two model heater using the same ratio discussed in 1 and 2. (Note this is A_{C18} and A''_{C19} in Attachment 6).

$$\frac{A_{C18}}{N_{18}} = \frac{A''_{C19}}{N_{19}}$$

The final equations for proportioning the heat transfer area in the condensing area zone are as follows:

$$AC_{19} = AC'_{19} + AC''_{19}$$

$$= \frac{N_{19}}{N_{18}} \times A_{DC18} + \left(A_{CTOT} - \frac{N_{19}}{N_{18}} \times A_{DC18}\right) \frac{N_{19}}{N_{TOT}}$$

$$AC_{18} = AC_{TOT} - \frac{N_{19}}{N_{18}} \times A_{DC18} \quad \frac{N_{18}}{N_{T}}$$

The composite calculation for the overall TTD was accomplished by using the operational equations: the 88 series cards.

After the model was designed we still had one major problem to overcome. PEPSE's calculated pressure drop in the desuperheating zone was greater than what the vendor claimed. We traced this problem back to the design of the desuperheating zone.

Over the past few years a number of improvements have been made by the manufacturers to the design of the shell side of the heaters. The manufacturers are becoming more concerned with the steam side pressure drop through each zone, especially the desuperheating zone. As the pressure drop through the desuperheating zone decreases, the available steam energy which was otherwise lost is now available for heat transfer to the feedwater. This improves the heater's terminal temperature difference and hence, its efficiency and effectiveness.

The conventional desuperheating zone uses single segmental baffles (Attachment 7). Although these baffles are functional to direct the steam across the entire tube bundle, they produce a rather high pressure drop. The pressure drop in the desuperheating zone is related to the amount of cross flow, and the outside tube fouling factor. For a given tube material the fouling factor is a constant and cannot be changed, but the amount of cross flow can.

The amount of cross flow in the desuperheating zone is dependent on three parameters:

1. The number of rows of tubes available for cross flow. This is the number of rows of tubes a stream of steam will sweep across as it travels through the zone. If we decrease this number, the zone pressure drop will decrease because the steam will cross less tubes.

2. The number of baffle plates. If we decrease this number, the pressure drop will decrease because the steam will not cross over the tubes as often as it travels thru the heater.

3. The flow area around a baffle plate. This is commonly referred to as baffle window area. If we increase this value the pressure drop will decrease because the steam will be deflected less as it travels around the baffle plates.

Consider, for example, the effect of changing the three parameters using the PEPSE feedwater heater design mode on a high pressure feedwater heater with a flow of 1,500,000 lbs/hr:

1. Decreasing the number of rows of tubes available for cross flow by just 2 rows decreased the terminal temperature difference by 0.25^{o}F.

2. Decreasing the number of baffles by one decreased the TTD by 0.5^{o}F.

3. Increasing the flow area around the baffle plate by one square foot decreases the TTD by a small amount of 0.01^{o}F.

Therefore we have shown that in the PEPSE program changing the number of rows of tubes available for cross flow and changing the number of baffles has the greatest affect on the heaters terminal temperature difference while changing the flow area around the baffle plate does not seem to affect it appreciably.

Although a 0.5^{o}F change in TTD on a high pressure heater in the seven feedwater heater 350 MW unit we analyzed does not seem like much, it does affect the unit heat rate by about 1.0 Btu/kwh. Over the course of one year a 0.5^{o}F TTD would increase fuel costs about $8,000 assuming a 100% capacity factor. Therefore, if the TTD on one high pressure heater were increased just 2^{o}F this would result in additional fuel costs of approximately $32,000.

To change the amount of cross flow the baffle arrangement must also be changed. Today, the heater manufacturers use a variety of baffle arrangements in the desuperheating zone to minimize the pressure drop: (See attachment 8)

1. Single segmental (conventional)
2. Double segmental
3. Triple segmental
4. Grid

The grid design produces the least pressure drop in the desuperheater zone, (approx. 0.2 psi) according to the vendors calculations. The steam flow is almost all parallel in this design because it only sweeps across one row of tubes as it travels through the zone.

PEPSE assumes a conventional vertical single segmental baffle arrangement and will calculate a zone pressure drop which is greater than that of the vendors unless the cross flow parameters which are mentioned above are adjusted.

The solution to the pressure drop problems was to use the above parameters to adjust the pressure drop calculated by PEPSE to match the vendors claim through each zone. Although this involved some approximation, the best heater designs i.e. those with the most effective heat transfer area and best baffle designs, achieved the best PEPSE results.

The last topic of consideration is the possibility of steam side condensation in the desuperheating zone outlet. If the steam leaving the zone is near saturation, serious tube erosion can occur which will significantly reduce the life of the heater. For this reason the steam leaving the desuperheating zone must have at least $2^{o}F$ of superheat* (Attachment 9).

It is very difficult to manually calculate the exact value of the steam temperature leaving this zone since not all of the feedwater passes through the long drain cooler (Attachment 10). Consequently the water which passes through the drain cooler could be as much as $15^{o}F$ cooler than the water that does not. This difference could cause local condensation in the desuperheating zone outlet.

The PEPSE feedwater heater design mode assumes that the steam leaving the desuperheating zone is at its saturation point. This is a good approximation for heat transfer calculation purposes but does not tell the engineer, who is also concerned about heater tube integrity, enough about what is actually happening in the zone.

* EPRI Guideline

The issue of condensation in the zone was discussed with the vendors but inconsistent answers were received. This could depend on the vendor's desuperheating zone construction and baffle arrangement. Therefore, it seems as though some vendors may be having trouble with this issue. This topic should be kept in mind when analyzing a heater with a long drain cooler.

In summary, a modern utility needs a method of comparing various vendors bid proposals on high pressure heaters. Performance must be considered as well as cost. Overall, PEPSE has the ability to assist the engineer in his analysis in making a more informed decision on the most cost effective heater to purchase.

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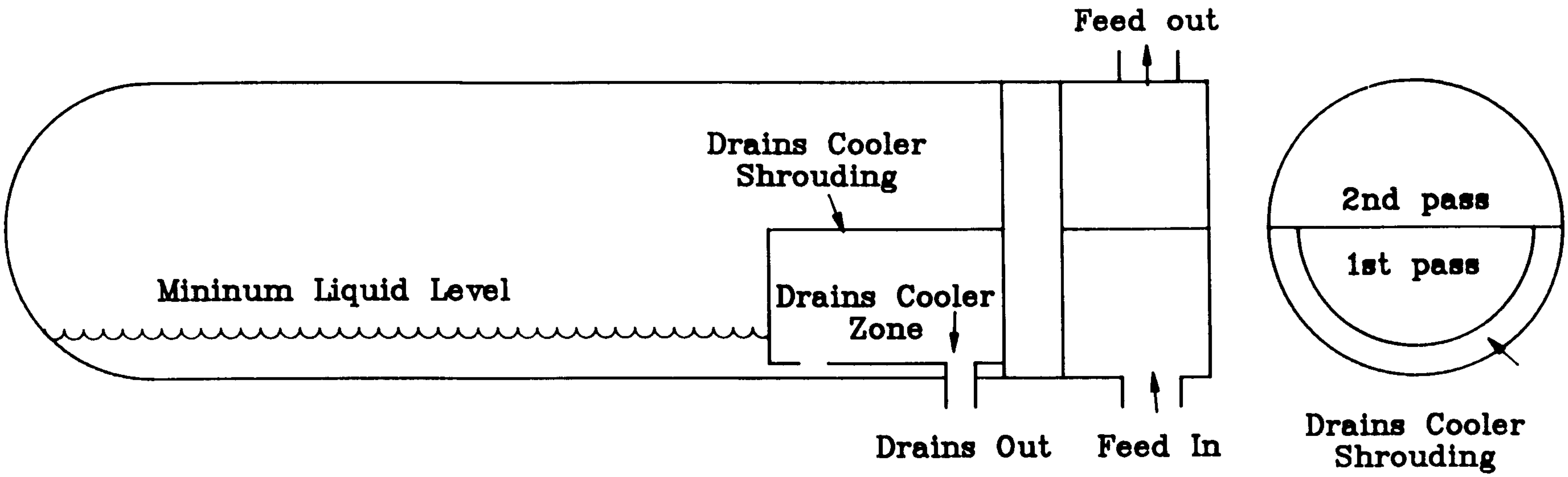
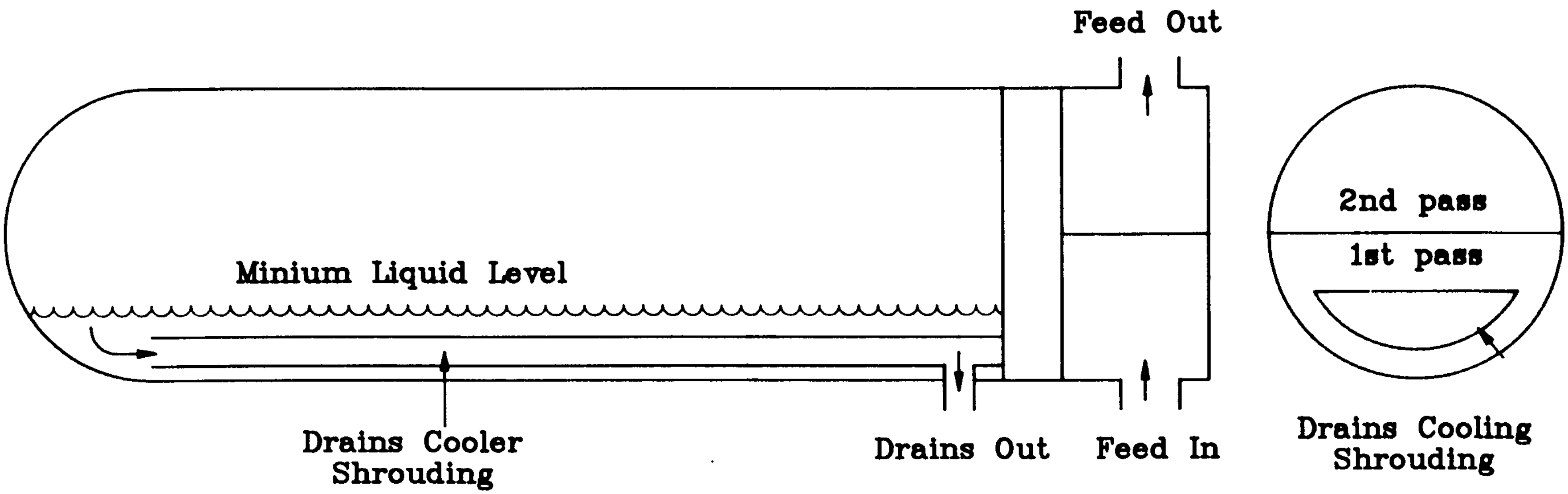


Short Drain Cooler Design

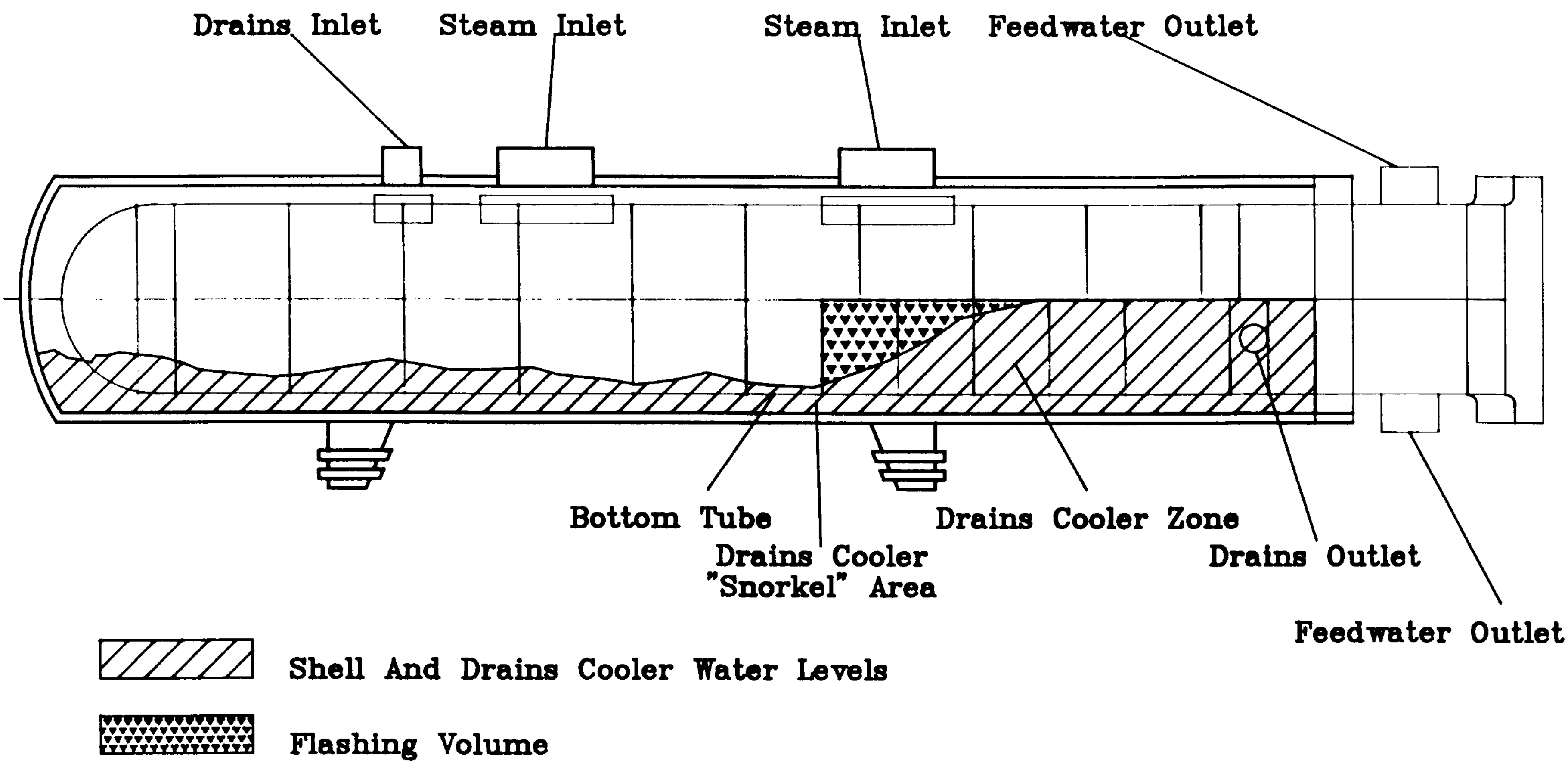


Long Drain Cooler Design

Drawing Courtesy of EPRI

Attachment 1

SHORT DRAIN COOLER
Low Shell Water Level With Side Drains Outlet

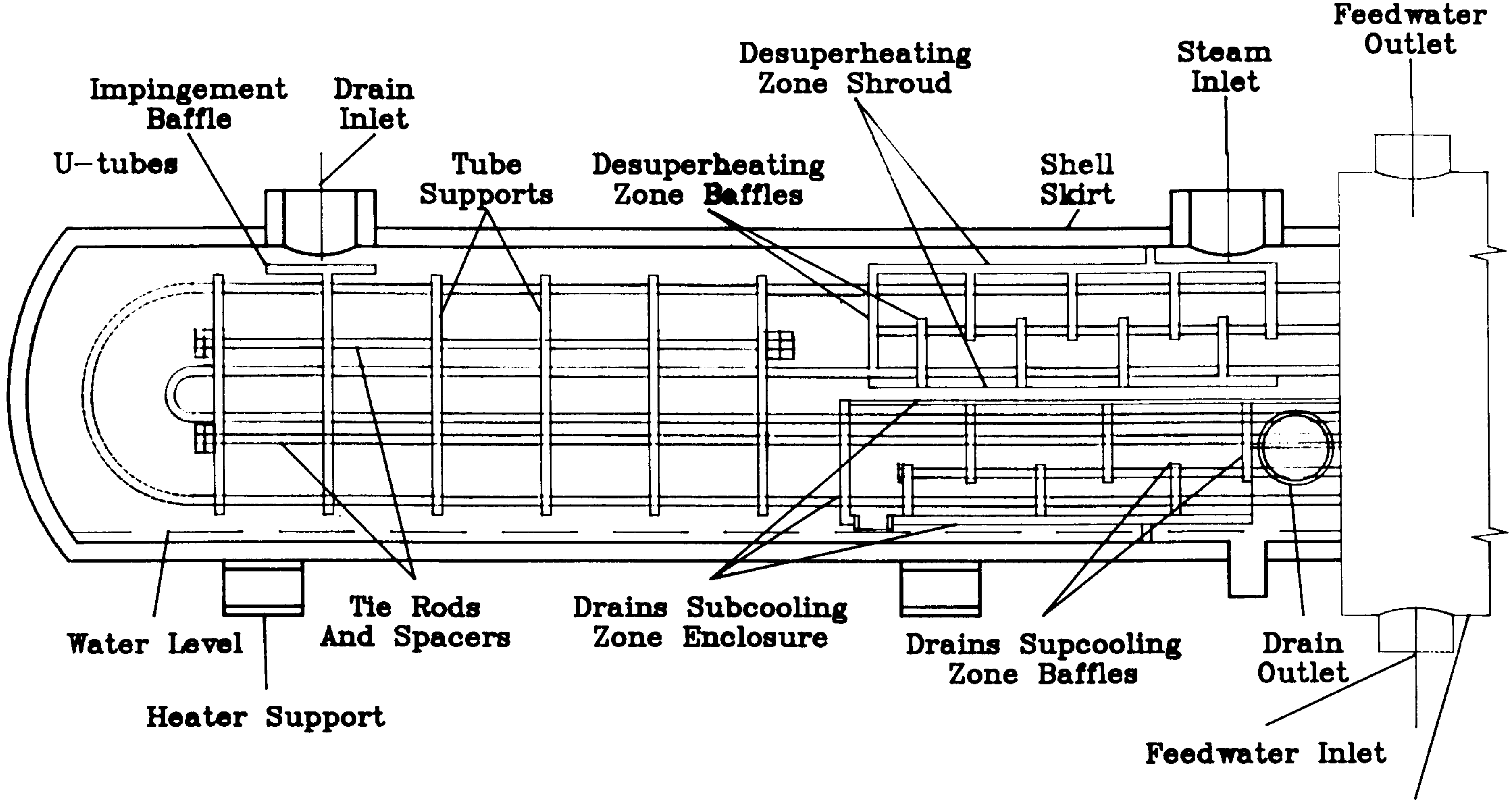


Drawing Courtesy of EPRI

Attachment 2

3–ZONE FEEDWATER HEATER WITH SHORT DRAIN COOLER

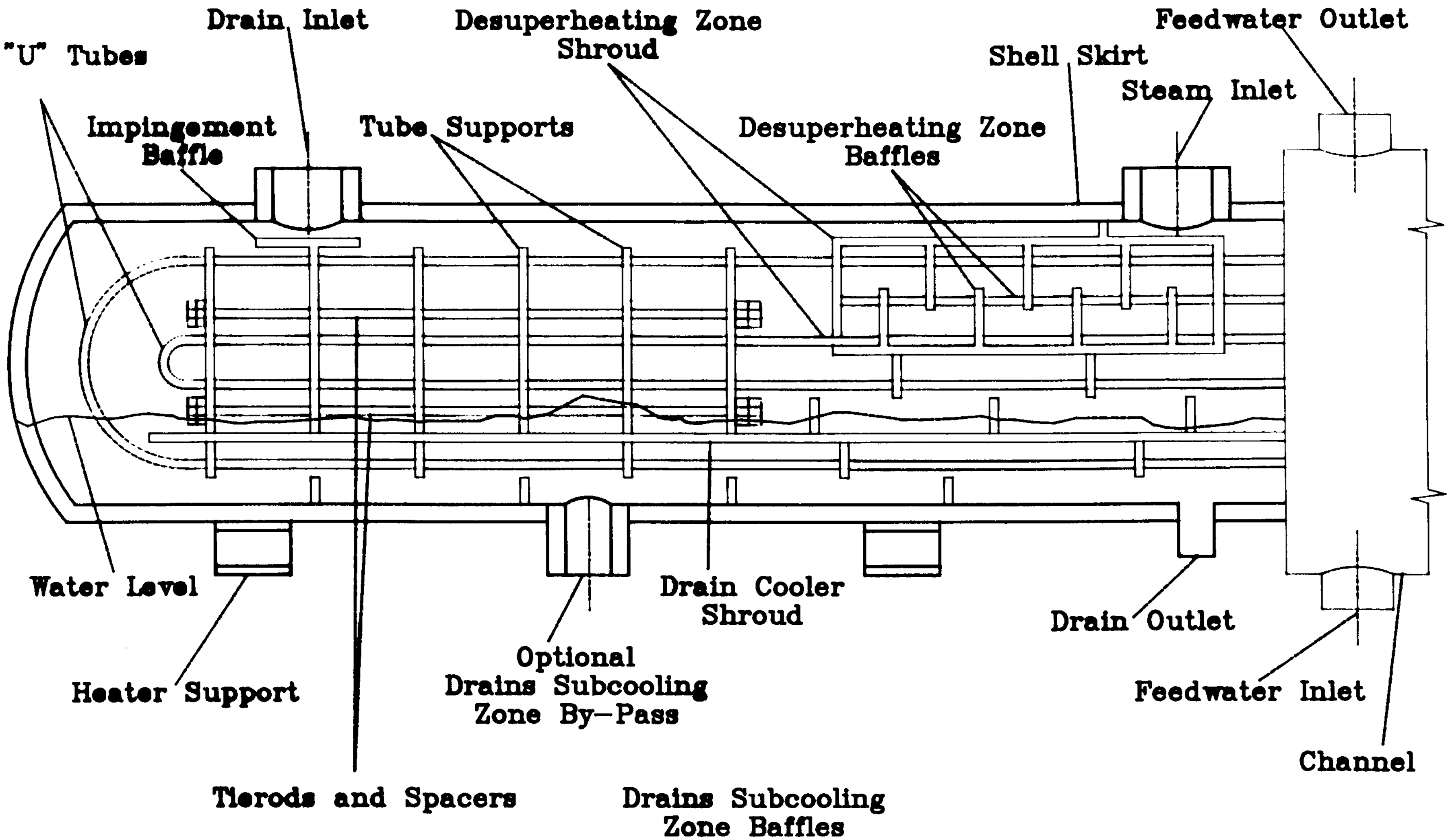
(Desuperheating, Condensing, and Subcooling Zones)



Drawing Courtesy of EPRI

Attachment 3

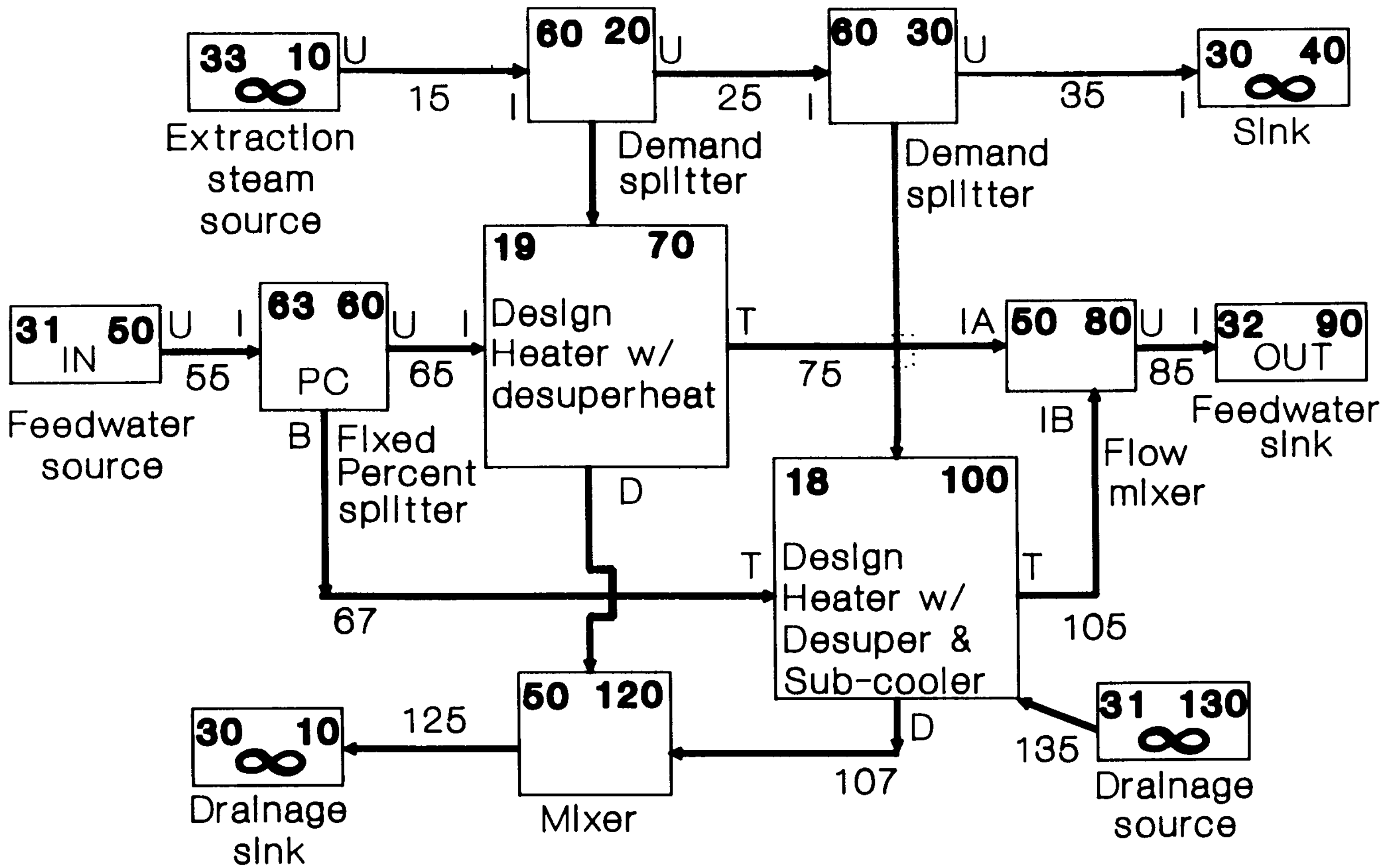
3–ZONE FEEDWATER HEATER
WITH LONG DRAIN COOLER
(Desuperheating, Condensing and Subcooling Zones)



Drawing Courtesy of EPRI

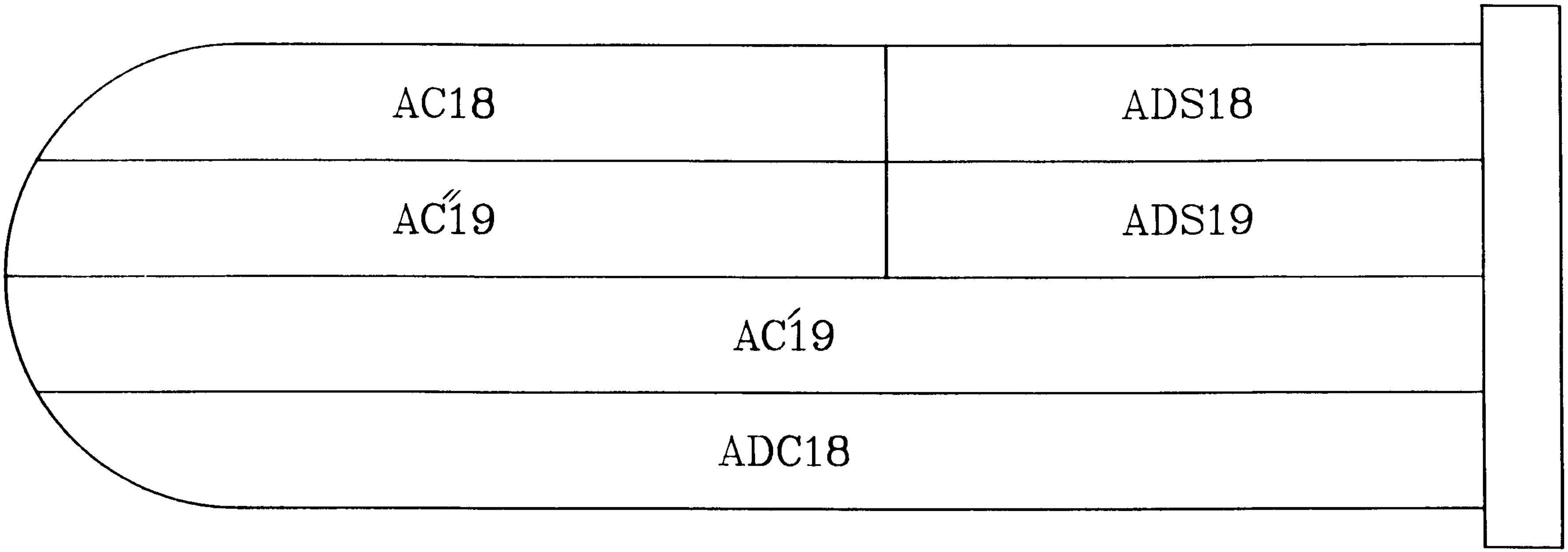
Attachment 4

FEEDWATER HEATER DESIGN SIMULATION SPLIT-PASS DESIGN MODEL



Attachment 5

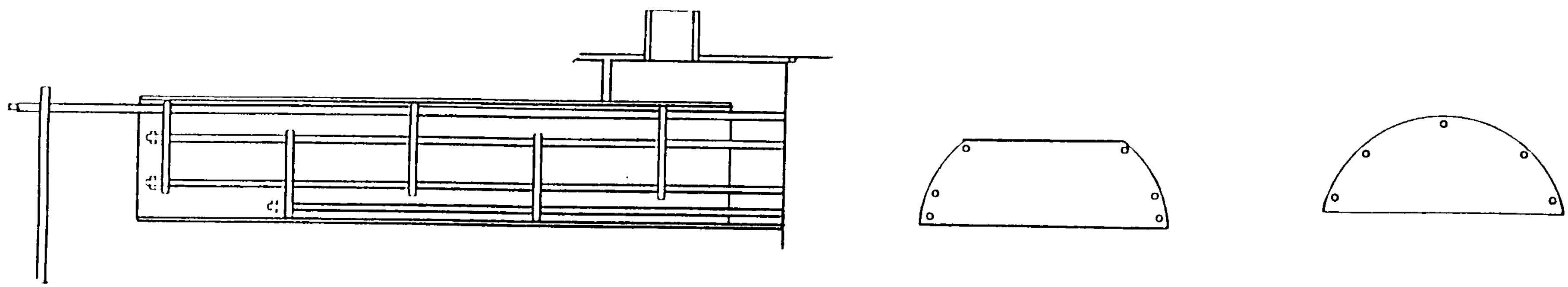
HEAT TRANSFER SURFACE AREA BREAKDOWN FOR SPLIT–PASS HEATER SIMULATION



ADS19 = Desuperheating Area
A′C19 = Condensing Area 19′
A″C19 = Condensing Area 19″
AC19 = A′C19 + A″C19 (total Condensing Area)
AC18 = Condensing Area 18
ADS18 = Desuperheating Area 18
ADC18 = Draincooling Area 18

Attachment 6

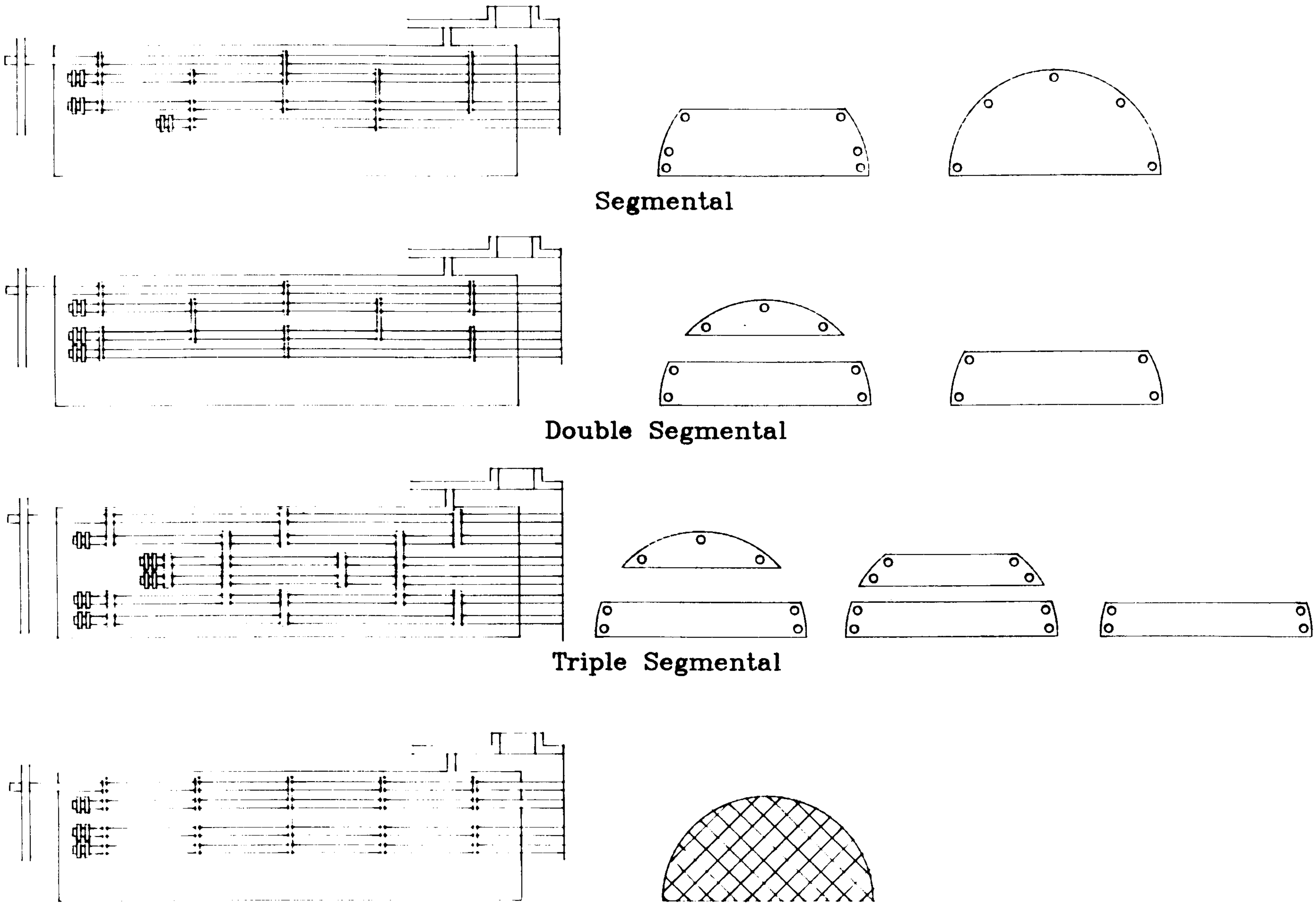
FEEDWATER HEATER DESUPERHEATING ZONE WITH
SINGLE SEGMENTAL BAFFLE PLATES



Drawing Courtesy of EPRI

ATTACHMENT 7

Desuperheating Zone Baffle Types



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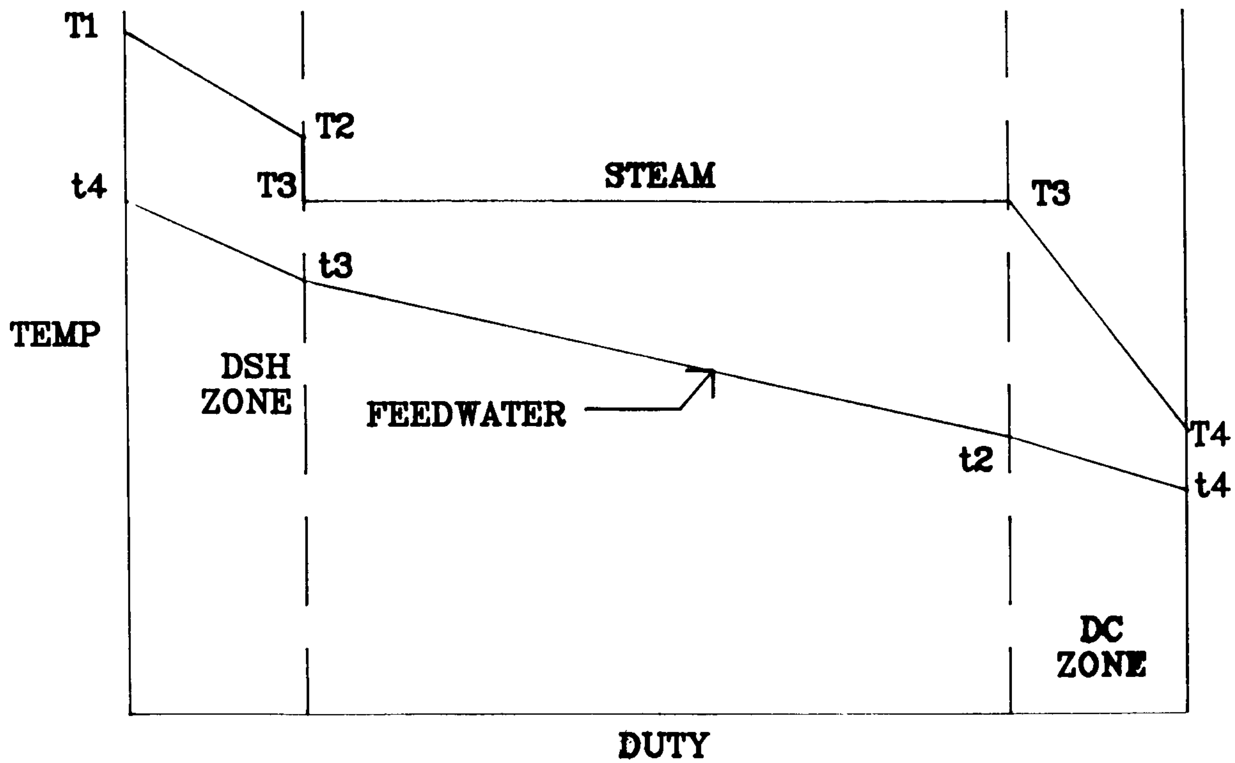
Attachment 8

TEMPERATURE DUTY DIAGRAM
THREE ZONE FEEDWATER HEATER

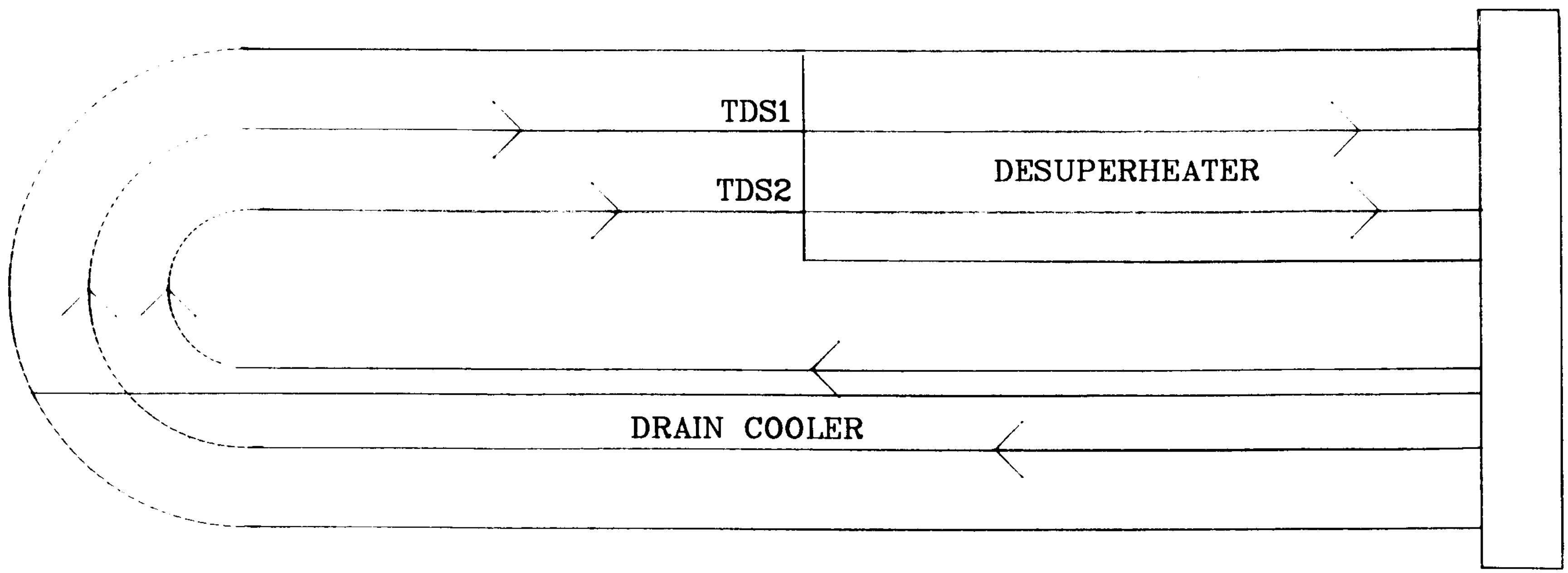


T1 = STEAM INLET TEMPERATURE
T2 = STEAM OUTLET TEMPERATURE FROM DESUPERHEATING ZONE
T3 = STEAM SATURATION TEMPERATURE IN CONDENSING ZONE
T4 = SUBCOOLING CONDENSATE OUTLET TEMPERATURE
t1 = FEEDWATER INLET TEMPERATURE
t2 = FEEDWATER OUTLET TEMPERATURE FROM DRAIN COOLING ZONE
t3 = FEEDWATER OUTLET TEMPERATURE FROM CONDENSING ZONE
t4 = FEEDWATER OUTLET TEMPERATURE FROM DESUPERHEATING ZONE

Drawing Courtesy of EPRI

Attachment 9

FEEDWATER HEATER WITH LONGDRAIN COOLER



TDS1 < TDS2

Attachment 10