REHABILITATION OF HEAT EXCHANGE EQUIPMENT
A KEY TO POWER PLANT LIFE EXTENSION AND PERFORMANCE IMPROVEMENT

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With the current evolutions of the energy market and the life extension of the power plants, all the equipment initially supplied need one day or another partial or total rehabilitation. For heat exchange equipment, this includes the condensers, feed water heaters and various heat exchangers. Modernisation is in particular necessary when in-service monitoring and periodic inspections show significant deteriorations of the tubes and cooling water leakages leading to forced outages or when tube and tube plate materials are no longer suited to cooling water characteristics or to updated specifications of the secondary system.

Feedwater heaters and heat exchangers damaged by erosion/corrosion, vibrations, etc. can be re-designed, manufactured and replaced easily. The operation is more complex on condensers and requires technical surveys, study of alternative solutions and has a more direct impact on the global output of the power plant. That is why our conference will focus on the condenser refurbishment.

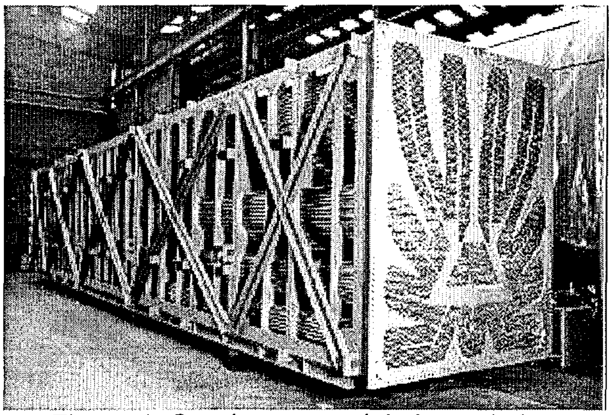


Figure 1. Condenser module in workshop

The revamping methods

Several solutions are available, which we describe below, but only the last one "modular revamping" answers the requirements of the power plant operators, as to upgrading and reliability over the whole life of the power plant.

Traditionally, our Company, as other Companies in the field, has carried out partial or total retubings of heat exchange equipment. In the middle of the 80's, we made an important step forward in implementing the modular technique for the replacement of condensers of any size. And this was a challenge. This modular technique was first implemented on the French nuclear plants of the 900 MW range, then extended to 1,300 MW condensers (Nogent). We now use this modular technique in the construction of new condensers for its numerous advantages, up to 1,450 MW condensers (N4 : Chooz and Civaux).

- <u>Retubing as original</u>

  This is the single tube-by-tube retubing using new tubes in the same material as the original one. This solution is only selected if the original material has been satisfactory (acceptable cost/operating life ratio). It can be selected in case of accidental damages to the tube bundle.

  Limits : This solution cannot answer modifications of the operating conditions : if the steam generator has been upgraded to 105 % of its initial value, the retubed heat exchanger will not possibly fill in its role without operating problems. This solution does not involve new technologies, new design rules or materials and is not the right answer to requirements of reliability over an extended life.

- <u>Retubing with a different tubing material</u>

  When the tube bundle degradation is related to permanent phenomena (such as erosion or corrosion) or if the original material is no longer adapted (modification of cooling water characteristics or need for copper elimination), the utility can select a retubing with a new tube material, without modification of the tube bundle layout. In this case, one has to act carefully and estimate the possible power losses due to the modifications of the heat exchange factor as well as the possible future problems of tube vibration.

  Additional conditions must be fulfilled :

  - Other condenser components, especially tubesheets, must be in a good condition to allow a satisfactory retubing operation ;
  - Number and spacing of tube support plates should not lead to a risk of vibrations for the new tube bundle. For instance, in the case of retubing copper alloy tubes with thin-wall titanium tubes, the vibration calculations lead generally to a tube support plate number larger than in the existing condenser. Therefore, retubing would be ruled out, except if staking, possibly on a large scale, is acceptable.
  - In addition to retubing (as original or with a new tubing material), other improvements can be carried out, such as tubesheet coating to protect the tubesheet and multigrooving of the holes (which can be easily carried out on site) to improve the tightness of the tube-to-tubesheet joint.

- <u>In-place reconstruction</u>

  This solution consists in re-engineering the whole equipment and rebuild at site a newly-designed condenser. It enables to increase the equipment performances using new technologies and providing a new design taking into account experience feedbacks.

  This solution is technically optimal, but obviously keeps the plant in outage for too long a period and will then only be selected if prefabrication is not possible (for instance if module access is precluded because of transportation difficulties between the workshop and the power plant) or when it is impossible to slide the modules in the plant (due for example to the civil engineering design).

<u>The modular solution</u>

Condenser modular refurbishment as developed by our Company consists in overhauling the existing condenser with complete tubed modules constructed in workshop and transported to the power plant where they are inserted into the condenser in place of the existing tube bundles.

This solution enables to completely modify the tube bundle design (tube and tubesheet materials, heat exchange surface, tube bundle layout, number of tube support plates), to improve performances or at least to offset the possible performance decrease due to a tubing material change and, generally speaking, to solve the problems incurred during the power plant operation.

The modular solution furthermore allows for a better fabrication quality than on site (for example, when thin-wall titanium tubes are welded to titanium tubesheets, which must be done in a clean room) and a reduction of the site work time.

Technical problems solved by the modular revamping – Common to all projects

- *Turbine exhaust pressure higher than expected (related to the heat load and the flow and temperature of the circulating water) which can result in losses of output :* a difference of 5 mbar in the nominal exhaust pressure of a turbo-generator unit results in losses of output, from about 1 MW in a 330 MW fossil-fired power station to 5 MW in a 900 MW PWR nuclear plant.

- *High oxygen level in the condensate* : if this oxygen level is not obtained at the condenser outlet by an appropriate design of tube bundles and adequate air extraction equipment, it is necessary to completely deaerate the water leaving the condenser by injecting auxiliary steam into the condenser hotwell, with some loss of output. The modular renovation of the Unit 1 condenser at the Dampierre Power Station on the banks of the River Loire (PWR 900 MW), allowed the elimination of deaerating equipment in the condenser hotwell, resulting in a gain in output of 7 MW.

- *Damages to the condenser tubes :* erosion/corrosion, abrasion, breaks due to vibration, etc. which require adapted answers, such as replacement of copper alloy tubes in the air cooling section corroded by ammonia, protection of peripheral areas eroded by high-velocity wet steam, installation of filters in the cooling system...

- *Leakage of cooling water into the condenser shell :* due to damaged tubes or defective tube-to-tubesheet joints. This is specially detrimental if the condenser is cooled by sea water.

- *Copper alloy tube bundles in condensers for PWR nuclear power stations*
  Experience has shown that copper deposits cause damages to the steam generators in nuclear power plants of the PWR type. Copper tubes have then to be replaced by stainless steel or titanium tubes. Elimination of copper alloys in the secondary circuit also enables to operate the feedwater system with a higher pH, thus minimising corrosion attacks in the feed heating plant and steam generators.
  Too high copper rejects are also harmful for the environment. If this problem occurs, measures must be taken to avoid copper particles to be rejected in the rivers.

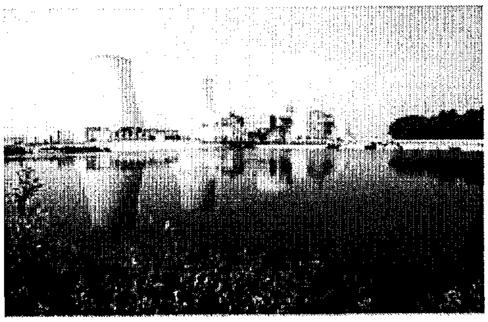


Figure 2. Nogent-sur-Seine, France (2 x 1,300 MW PWR)

Particular site configurations – Specific responses

From our 15 years' experience in condenser rehabilitation in modules, we have gained a wide knowledge on all types of site configurations, covering probably all difficulties that can be found during site interventions on existing equipment :

- Our experience has enlarged our capacity to cope with various arrangements of the machine room (small space in front of the building, use of large cranes, condenser installed several metres below the ground level...) ;
- We have the know-how of handling of modules with several shapes and sizes (as heavy as 140 tons, as high as 10 m, as long as 19 m) transported by various means, on land and water ;
- We have references in various outputs and types of power stations (fossil, PWR, BWR, VVER) from 220 to 1,300 MW, and in the rehabilitation of condensers initially supplied by another company (see our list of references on pages 10 and 11).

Straight access
Dampierre 1, France (900 MW PWR), operated by EDF

This first example is a standard case when there is enough room in and in front of the turbine building to extract the old tube bundles and insert the new modules without particular difficulties.

The constraints of time schedule (site works to fit in the outage period needed for steam generator replacement) and the possibility to improve overall tube bundle performances led EDF to undertake a complete revamping using the modular technology.

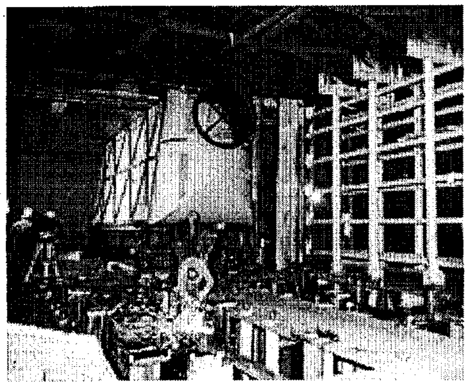


Figure 3. Dampierre 1 – Condenser module introduction

In 1990, EDF decided to change the brass tube bundles of Dampierre 1 after about 70,000 working hours, to protect the new steam generators against any chemical pollution (copper or oxygen). The tube bundles showed the different types of deterioration already observed in other units of the CP1 programme : impingement tube erosion, internal tube abrasion, ammoniacal corrosion of air cooler tubes.

Various additional technical improvements were included in the revamping operation to increase the equipment performances, such as the replacement of LP1 heater brass tube bundle by 304L stainless steel tubes in order to eliminate any trace of copper in the secondary circuit, the modification of the bled steam pipe No. 2 layout to reduce steam pressure drop in the condenser exhaust neck, the modification of the ball cleaning system, the installation of a helium test device, the installation of magnetic filters in hotwell bottom, the installation of a hydraulic guard on the condenser-turbine expansion joint and the fitting of additional measuring instruments.

Further to the analysis of the dismantling work around the condenser and LP1 heaters, it has been necessary to modify all the piping isometric layout, to locate on site the cables and small pipes not listed and to set up temporary new sections to keep certain general service systems working (compressed air, ventilation, fire protection).

Considering the large number of people working at site in the condenser, special measures were taken to guarantee a high level of security, such as the installation of a gas extraction system or the centralisation of hygiene and security programmes.

The module handling, both inside and outside the machine room, was undertaken by means of a multi-directional trailor. The main features of the site works included:

- Preparation of the area around the condenser in order to facilitate the removal of the existing bundles and the insertion of the new modules,
- Installation of the LP1 heaters in the condenser neck,

- Completion of certain modifications inside the neck, concerning the bled steam pipe No. 2, air extraction pipes, make-up water pipe...
- Preparation of the new tube bundle installation.

This preparation consisted mainly of :

- Blocking the turbine/condenser expansion joint,
- Installing support for the LP steam by-pass diffusers,
- Cutting out the existing water-boxes and dismantling certain parts of the inlet and outlet cooling water pipes (bends, ball cleaning system sleeves, expansion bellows...),
- Stiffening the existing tube bundles for modular extraction,
- Cutting the connections between the existing modules and the exhaust neck, shell and hotwell,
- Laying the necessary sliding rails and supports for handling inside the hotwell as well as vertical props for the new modules.

After extraction of the existing bundles, the new modules were brought into the machine hall by trailor, positioned opposite the condenser after a 90° rotation, then put onto hydraulic jacks, placed on the rails, inserted and set into final position.

After dismantling the components used for handling, the connections between modules and condenser were established, the condenser walls closed, the inlet water-boxes fitted and surroundings restored.

After recommissioning, the tube bundle sealing was tested by injecting helium into the circulating water and tracing possible leaks at vacuum pump discharge. Then the performance tests checked the following guarantees :

- The condensation pressure above the tube bundle,
- The condensate oxygen content,
- The cooling water pressure drop between inlet and outlet water-box flanges,
- The condensate sub-cooling.

These tests showed that, compared to the previous tube bundles, the new ones ensure better condensate deaeration leading to a gain of about 7 MW, which corresponds to the shutdown of the auxiliary deaerating steam. All things being equal and at nominal conditions, the new design with radiant-type tube bundles also improves the vacuum by 4 mbar, i.e. a new power gain of 4 MW.

Note that a simple retubing with stainless steel tubes would have entailed a power loss of 5 MW compared with the previous layout (loss due mainly to a lower thermal conductivity).

Restricted access due to outside obstacles
Almaraz, Spain (2 x 900 MW PWR) operated by CNA

In this operation, the arrangement of the power station, the location of external items such as the electric transformers, the beams and steelworks of the turbine hall, the ground resistance have represented major challenges.

In order to allow the replacement in a time as short as that imposed by the programmed shutdown of the unit (maximum time allowed for the installation of the four modules per unit was 26 days), it was necessary to prepare meticulously all the retrofit operations. Particularly, during the design period, precise measurements were made at site to ensure the environment knowledge and to define the handling, step by step, as well as the erection sequence. For the same purpose, a first intervention on the condenser was carried out during a shutdown of the plant some months ahead of the main shutdown, in order to achieve in advance some preliminary reinforcements and modifications.

- Using a large capacity crane (800 tons) for the module installation and to reduce the handling time.

  This capacity was necessary because of the location of the condensers in a pit. It was the first time in all our experience when we had to use such large lifting equipment. In addition, the proximity of the electrical transformers of the plant made the task even more complicate. The distance between the wall which surrounds the transformers and the wall of the machine room building is smaller than the length of the modules. Consequently, the center of gravity of the modules was moved by adding additional weights at one end to allow a dissymetrical position of the supporting cables. Thus the new module could be introduced in the building without foul between the cables and the wall. When positioned in the axis, the module was laid down on the rails and pushed in place using hydraulic jacks.

Figure 4. Almaraz - Module handling

- Cutting the old tube bundles in two inside the condensers because of their weight (200 tons) and their dimensions, to obtain lighter structure parts that the crane can handle.
- Setting up a temporary support to maintain the structure weakened by the cuts and specially the feedwater heaters placed in the condenser neck.
- Temporary dismantling of the overhead wires coming out from the alternator for the installation of the 800 ton crane.
- The presence of underground cooling water ducts necessitated to take special precautions to avoid any load on the ground higher than the authorized one.
- On unit 2, temporary displacement of the stand-by electric transformers.

The site operations lasted 25 days and 15 hours for unit 1 and 22 days and 9 hours for unit 2, a record time for our Company, this time being measured from the authorization to enter the condenser on steam side, to the end of the hydraulic test after the condenser has been kept full of water during 12 hours.

The performance tests carried out on both units on the basis of the ASME Power Test Code 12-2 Standards showed that both condensers gave full satisfaction with measurement results better than the given guarantees for the vacuum (gain from 1 to 3 mbar depending on the test operating conditions), the condensate oxygen content (0.6 to 2 ppb versus 5 ppb) and the condensate subcooling (0.1 °C to 0.25 °C reheating versus 0.3 °C subcooling).

Furthermore, from the follow-up of the condenser operation by CNA, it appears that over a long period, the condensing pressure remains lower than the guaranteed value for the corresponding operating conditions and obviously better than the old condenser performances, enabling an electric output gain comprised between 1 and 3 MW for each unit, depending on the cooling water temperature.

Difficult access due to condenser arrangement in the turbine building
Bugey, France (4 x 900 MW PWR) operated by EDF

Two units are cooled in open circuit by the Rhone river water and the other two in semi-open circuit by cooling tower. EDF decided to refurbish the 4 condensers to increase the reliability and performance of its condensers, through an improvement of the tube bundle and a more efficient arrangement of the internal structures. The result proved very positive, as the renovated condenser helped improve the performances of the units by up to 12 MW.

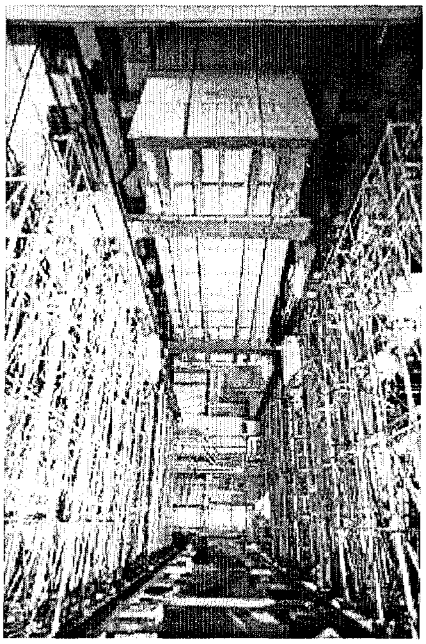
The site operations were particularly challenging as the condensers are installed below the ground level at minus 7 metre level.

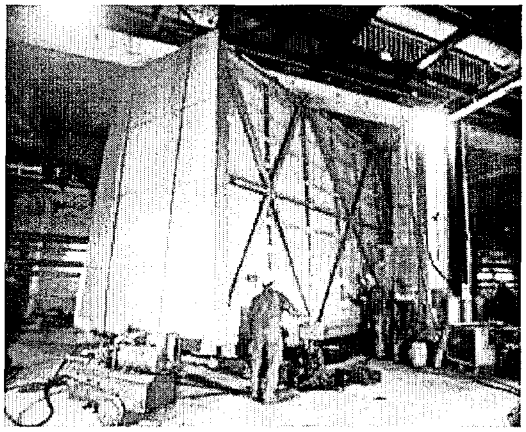
Preliminary studies carried out jointly by EDF and our Company had identified the obstacles to the installation of the new modules : pipes of various diameters, lines of cables, as well as the alternator coaxial sheathed cables and a huge reinforced concrete beam of 1.60 metres height, two items which had to be cut to give free access to the –7m level.

A guide structure was erected, designed to position the module straight over the handling shaft before lowering it down to –7m level. Tubular scaffoldings were used to reinforce the steelwork and to support the guide structure.

The site operations fit into the eleven week outage and included cutting and removal of the old bundles, handling and assembly of the new modules, structural modifications.

The handling was complex : the module was introduced into the machine room. Lifted by the overhead crane, moved slightly and then turned by 90°, it was put down on the trolleys of the guide structure. Unhooked from the crane and slowly pushed over the hole previously created after the concrete beam and the alternator sheathed cables have been cut, it was lowered down to the –7m level and put down on the sliding rails. Then it was turned very precisely by 90° by means of special devices called "turtles" before being slid into its final position.





Figures 5 & 6. Bugey – Module handling

Modular refurbishment : the best technico-economical solution

The supplementary costs incurred by a modular refurbishment instead of a simple retubing are shortly recovered as this optimised solution gives, according to our experience, a return on investment of 3 to 5 years.

No overcost is charged for shutdown extra time, as a modular revamping can fit in a regular outage for maintenance, provided that some preliminary operations be carried out, if necessary, during a previous outage.

The updated design provides better performances and brings savings on O&M costs : the new materials are more elaborate and adapted to the actual operating conditions ; the workshop manufacture respects strict quality criteria. All this ensures a guaranteed reliability over the remaining life of the power plant.

The modular solution we offer our customer is optimised for his particular case and takes all the parameters into account to meet his needs and objectives as to absolute reliability but also cost effective solution.

Figure 7. **ALSTOM Power Heat Exchange – List of references**

MODULAR REVAMPING (France)

UTILITY - PLANT YEAR OF ERECTION	POWER (MW) TYPE	ORIGINAL TUBING	REVAMPING	REMARKS
EDF - BUGEY 3 1990	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - DAMPIERRE 1 1990	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - BUGEY 2 1990	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - TRICASTIN 3 1992	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - TRICASTIN 4 1992/93	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - BUGEY 5 1993	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - TRICASTIN 2 1992/93	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - TRICASTIN 1 1994	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - DAMPIERRE 3 1995	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets
EDF - NOGENT 1 1998	1 300 N PWR	70/30 Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded & expanded into new solid 304L Stainless steel tubesheets
EDF - NOGENT 2 1999	1 300 N PWR	70/30 Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded & expanded into new solid 304L Stainless steel tubesheets
EDF - BUGEY 4 1999	900 N PWR	70/30 Ars-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 304L SS tubesheets

ALSTOM Power Heat Exchange – List of references (cont'd)

MODULAR REVAMPING (outside France)

UTILITY - PLANT YEAR OF ERECTION	POWER (MW) TYPE	ORIGINAL TUBING	REVAMPING	REMARKS
MYAPC - MAINE YANKEE (USA) 1985	870 N PWR	AL 6X	Titanium	4 modules - New tube bundle layout - Tubes welded to solid titanium tubesheets
INTERCOM - TIHANGE 2 (Belgium) 1989	900 N PWR	Al-Brass	316L Stainless Steel	6 modules - New tube bundle layout - Tubes welded to new solid 316L SS tubesheets
IVO - LOVIISA 2 (Finland) 1990	2 x 230 N VVER	Cu-Ni	Titanium	4 modules - New tube bundle layout - Titanium-clad carbon steel tubesheets
PECO - PEACH BOTTOM 2 (USA) 1991	1,100 MW N BWR	Ad-Brass	Titanium	6 modules - New tube bundle layout - Tubes welded to new solid titanium tubesheets
PECO - PEACH BOTTOM 3 (USA) 1991	1,100 MW N BWR	Ad-Brass /304 SS	Titanium	6 modules - New tube bundle layout - Tubes welded to new solid titanium tubesheets
EBES - DOEL 3 (Belgium) 1991	900 N PWR	76.22.2 Ars-Brass	Titanium	6 modules - New tube bundle layout - Tubes welded to new solid titanium tubesheets
NEK - KRSKO (Slovenia) 1992	632 N PWR	90/10 Cu-Ni/304 SS	316 Stainless Steel	4 modules - New tube bundle layout - Tubes welded to new solid 304 SS tubesheets
CNA - ALMARAZ 1 (Spain) 1995	900 N PWR	Ad-Brass	Titanium	4 modules - New tube bundle layout - Tubes welded to new titanium-clad carbon steel tubesheets
CNA - ALMARAZ 2 (Spain) 1995	900 N PWR	Ad-Brass	Titanium	4 modules - New tube bundle layout - Tubes welded to new titanium-clad carbon steel tubesheets
TRACTEBEL - DOEL 4 (Belgium)	900 N PWR	Titanium	Titanium	4 modules - New tube bundle layout - Tubes welded to new solid titanium tubesheets
SCOTTISH HYDRO - PETERHEAD (Scotland) 1997	2 x 600 Fossil	Al-Brass	Titanium	4 modules - New tube bundle layout - Tubes welded to new solid titanium tubesheets
PAKS NPP - PAKS 1-4 (Hungary) 1997/2000	4 x 440 N VVER	Cu-Ni alloy	316L Stainless Steel	4 modules per condenser - 2 condensers /unit New tube bundle layout - Tubes expanded & welded to new 316L SS tubesheets
ALCAN – LYNEMOUTH 1-3 (UK) 2001-2002	3 x 140 Fossil	Cu-Ni alloy	Titanium	2 modules per condenser New tube bundle layout - Tubes welded to new solid titanium tubesheets

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