# INTERMEDIATE HEAT EXCHANGER FOR HTR PROCESS HEAT APPLICATION

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## 1. SUBJECT.

In the French study on the nuclear gasification of coal, the following options were recommended :

- Coal hydrogenation, the hydrogen being derived from $CH^4$ reforming under the effects of HTR heat.
- The use of an intermediate helium circuit between the nuclear plant and the reforming plant.

The purpose of the present paper is to describe the heat exchanger designed to transfer heat from the primary to the intermediate circuit.

## 2. PRELIMINARY CHOICES.

The power level of the largest reforming plants corresponding to the present hydrogen output is approximately 200 MW. Keeping the same basic power level and assuming that 4 heat exchangers can be placed round the reactor core, we arrived at an 800 MW power level for the reactor. Taking Fort St VRAIN as reference plant (840 MW), this gives four 210 MW lines, which corresponds to the power level of the intermediate heat exchanger here described.

### 2.1. Main options (slide 1).

The present heat exchanger study is based on the following design options :

- The primary helium flows upwards in the IHX because it flows downwards in the reactor core.
- The primary helium flows outside the exchanger tubes, because it is easier to keep the primary helium in the prestressed concrete reactor vessel liner, rather than inside the tube bundle, where thermal expansion problems would arise.
- The heat exchanger is of the "once through" type, but the intermediate helium inlet and outlet are both located on the same side and as near as possible to the fondation raft in order to mitigate seismic problems. With a once-through device, the pressure drop is lower and in-service inspection is easier.
- The hot parts are made of Incoloy 800 H. We shall come back on this option later.

### 2.2. Main design criteria (slide 2).

In accordance with other reactor data, the heat exchanger is designed for :

- An upper helium temperature of 850°C for the primary circuit and 800°C for the intermediate circuit. These are not in fact extremely high temperatures, but combined with the other operating parameters (70 bar and a 300.000 hour lifetime) the mechanical resistance requirements are relatively difficult to comply with. These temperatures, together with the flow-rate, determine helium lower temperatures of 480°C for the primary circuit and 350°C for the intermediate circuit.

- A 70 bar pressure in the primary circuit and 72.5 bar pressure in the intermediate circuit. These values are high enough to permit a low pressure drop and consequently, a low blower power level.

- The pressure drop is limited to 800 mbar on the primary side and 1600 mbar on the intermediate side.

- The $\Delta P$ is calculated at 2.5 bar for normal conditions and upset conditions (intermediate depressurization accident) at 70 b 870° C for 1 hour.

2.3. Main design requirements (slide 3).

- The design concept has to allow for in-service inspection and the closing of a faulted tube.

- The design calculations are based on ASME and code case 1592, for a 300.000 hour lifetime. Provision is made for operation with 2 % of the tubes plugged.

# 3. DESCRIPTION.

## 3.1. Design (slide 4).

Taking into account the requirements described above and after some research into various possible solutions, we propose the following design.

Each of the 4 heat exchangers consists of 6 modules arranged round a central collector. The tube bundle modules are of the straight tube type. The primary (hot) helium enters at the bottom of the device, flows up outside the tubes and leaves the heat exchanger towards the main circulator at the top.

The intermediate (cold) helium enters the device at the bottom through an intake chamber located under the metal structure bounding the primary containment, flows up through a central collector, is distributed to each module by helicoidal subheaders and is warmed as it flows down to the lower cavity where it is collected.

The modules are fixed at the base to a support structure, the overall thermal expansion being accommodated at the top of the tube bundle where the tubes are unconstrained. The helicoidal subheader takes up the thermal expansion difference between the module and the central header. The support structure is insulated on the primary side to keep the metal part cool.

## 3.2. Construction (slides 5.6.7).

The module main characteristics are as follows :

- 10/14 mm Ø tubes, arranged in 21 mm triangular pitch bundles, having an exchange length of 11.2 m.

- The tube number is 1602. The heat exchange surface is 711 $m^2$ ; the primary helium flow area is 0.486 $m^2$ and that of the intermediate helium 0.126 $m^2$.

- The primary helium flow velocity is 14 m/s and that of the intermediate helium 29 m/s, which results in 40 mbar and 460 mbar respectively for the outside and inside bundle pressure drops.

- The module diameter is 920 mm and its weight 24.2 tonnes.

Further particulars of the module can be seen on slide 6.

The bundle tubes are welded at each end to tube sheets. An upper tank collects the cold intermediate helium and a lower tank, the hot intermediate helium.

The primary helium enters and leaves through a port provided in the outer shroud, which guides the helium flow. The shroud is reinforced every 700 mm by rings, which also support the tube bundle bracing grids, formed of two layers of cross rods, butt-welded to the ring. At the top, the shroud widens, in order to canalize the primary helium towards the circulator suction chamber.

The tubes are undulated at the top, to make allowances for differential thermal expansion, which, at the worst, can amount to 40°C.

On slide 7, you can see a general view of a heat exchanger.

The module support structure also bounds the primary containment. It has a convex base with 6 module seatings and one central collector, which also acts as a support for the modules and for the seismic buffers. The lower guide forms a separation for the hot primary helium and the upper guide forms a separation for the primary helium leaving the circulator. Provision is made for a slight helium leakage to the hottest areas of the system to adjust the temperature in the intermediate zone around the modules.

The intermediate helium outlet pipes are internally insulated and flanged onto the seatings provided. They act as thermal sleeves between the very high temperature elements and the module seatings.

Free expansion gaskets connect the hot intermediate helium header to the lower cavity, with a slight leak of cold into hot intermediate helium.

The intermediate helium cold collector is supplied from free expansion headers, which are connected to the central collector by 10 helicoidal sub-headers.

Each module can be extracted through the top of the penetration after removing the circulator and its helium suction devices.

One of our concerns with this design was to locate in the cold area structures subjected to severe mechanical stresses.

## SIZING.

### Thermal considerations.

The thermal sizing of this exchanger is based on heat exchange formulae found in literature on the subject. The helium characteristics taken are those published by the CEA.

A 12 % margin is allowed :

- 6.5 % for heat transfer coefficient uncertainties
- 2.5 % for inactive surfaces
- 2 % for plugged tubes
- 1 % for manufacturing allowances.

### Mechanical considerations.

The mechanical properties of the exchanger structures shall comply with ASME and code case 1592 recommendations. The materials selected are as follows :

- 2.½ Cr, 1 % Mo for the parts functioning below 400°C.
- Incoloy 800 H for the hot parts, which can reach temperatures up to 870°C.

Before deciding to use Incoloy 800 H, on the basis of references in the Wiggin catalogue, we made a comparison between the 800 H and 802, from which we reached the following conclusions :

- Incoloy 802 elastic limits are higher than those of 800 H.
- Incoloy 802 creep resistance is higher than that of 800 H for utilisation periods of less than 10.000 hours but this advantage is no longer apparent over longer periods.

We consequently selected Incoloy 800 H, with a view to basing the project on the most penalizing data.

For the coldest parts, we found all the requisite data in the ASME.

For the very hot parts, the admissible stress limits ($\sigma_{rupture}$, $S_m$, $S_t$) had to be obtained by extrapolation of the code case 1592 data, which only go up to 760°C.

The admissible stress limits are defined using the following values :

- For $S_m$
  - instant rupture stress versus temperature
  - yield stress versus temperature
- For $S_t$
  - stress initiating tertiary creep versus time and temperature
  - rupture stress versus time and temperature
  - stress resulting in 1 % creep versus time and temperature
- For 800 H at 870°C, the following data sources were available:
  - case 1592 for the yield stress only
  - a Wiggin catalogue for the yield stress, the rupture stress with time versus temperature, the stress resulting in 1 % creep with time versus temperature, but for periods of time less than or equal to 10.000 hours.
  - a creep law defined by the CEA and GAC.

The data derived from all these sources had to be extrapolated either for temperature (code case 1592) or for time (Wiggin) and the values selected were consistently the lowest possible.

As we had no data on the stress initiating tertiary creep, we applied a safety factor of 0.6 to 0.7 to $S_t$; this gave the curve shown in slide 9 which we used for our calculations. Slide 10 gives the rupture stress.

## CONCLUSION

This design study for an exchanger for HTR heat generating applications, using conservative material characteristics, has shown that it is presently possible to consider building such a component for temperatures of 870°C. It also evidences the necessity to focus efforts mainly on the materials used for very high temperature nuclear developments, particular attention being paid to the investigation of their characteristics versus temperature and time for periods of up to 300.000 hours. These materials should also include insulating materials.

### MAIN OPTIONS

Reactor with 4 heat exchangers

Primary helium flow upwards in the IHX

Primary helium flow outside the exchange tubes

Once through H.X.

Intermediate helium inlet and outlet located on the same side of the I.H.X. module

Structural material 800 h.

SLIDE 1

## I.H.X. DESIGN CRITERIA

| | | |
|---|---|---|
| Power | 210 | MW |
| Primary helium loop | | |
| temperature | 850/480 | °C |
| mass flow | 109,35 | kg/s |
| pressure | 70 | bar |
| pressure drop | < 500 | mbar |
| Intermediate helium loop | | |
| temperature | 350/800 | °C |
| mass flow | 89,92 | kg/s |
| pressure | 72,5 | bar |
| pressure drop | < 1600 | mbar |
| Normal conditions | $\Delta$ p = 2,5 | bar |
| Upset conditions | $\Delta$ p = 70 | bar at 870 °C during 1 hour |

SLIDE 2

## MAIN DESIGN REQUIREMENTS

Possibility of inservice inspection

Possibility of closing faulty tubes

Possibility of operating with plugged tubes

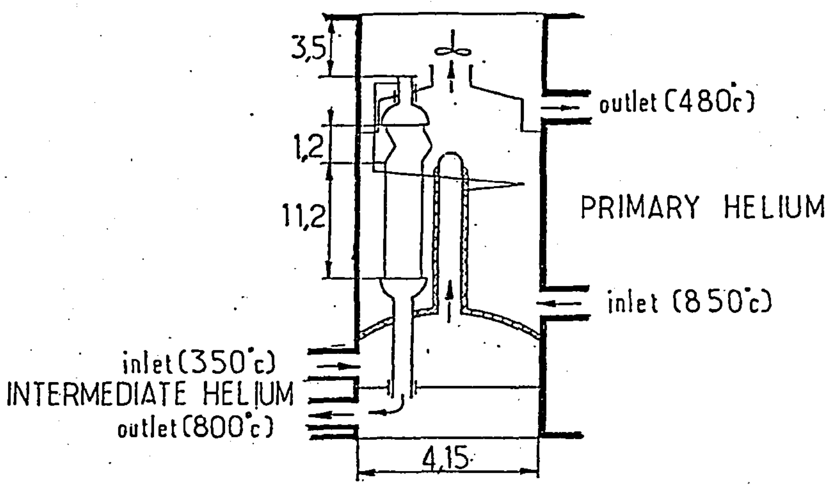
Design calculations made with ASME and Code Case 1592

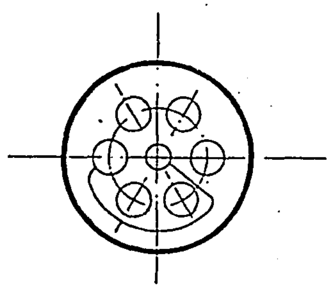
Life time 300.000 h.

Maximum dimensions compatible with transport possibilities

SLIDE 3

REFERENCE HEAT EXCHANGER



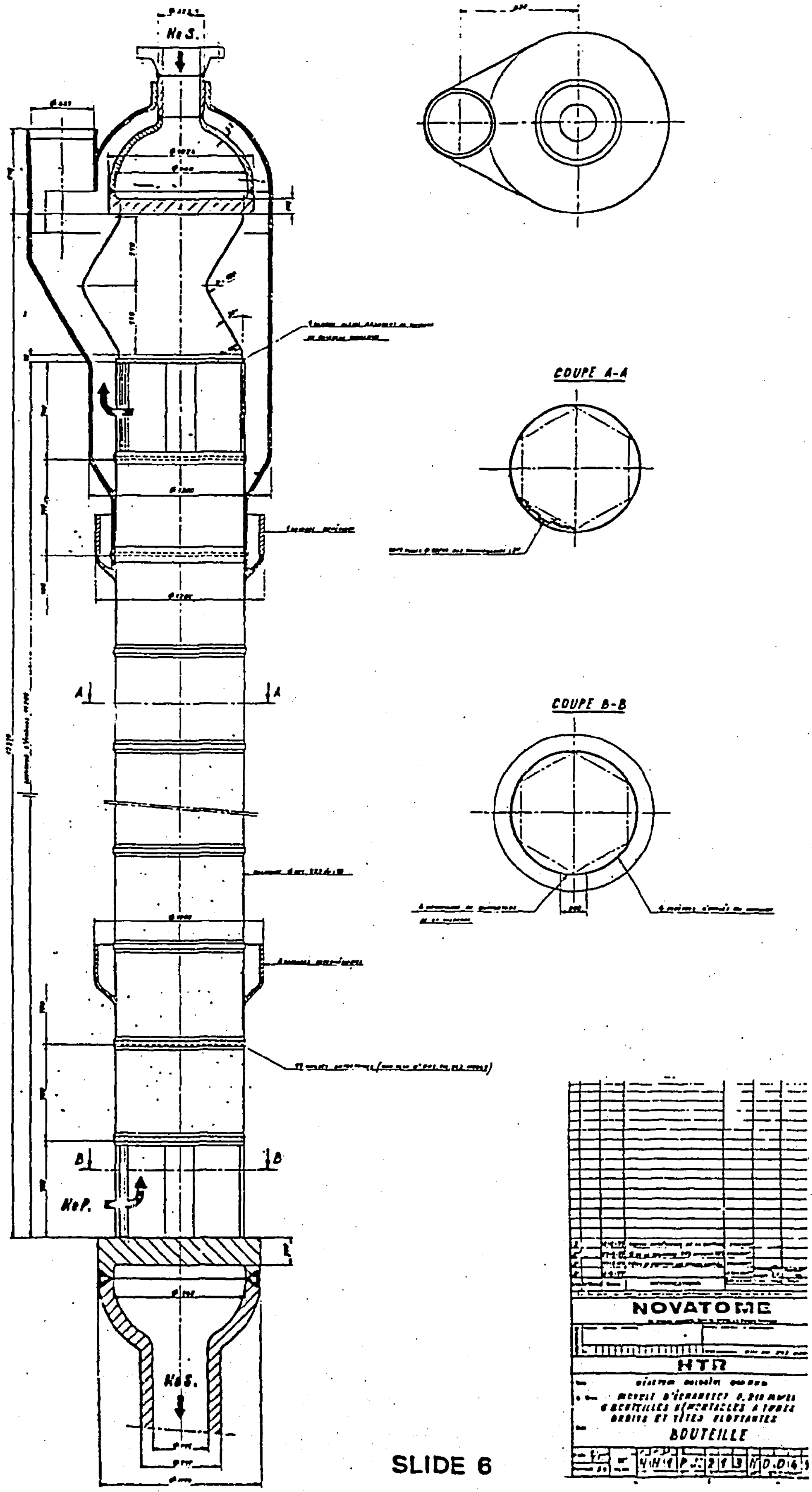



SLIDE 4

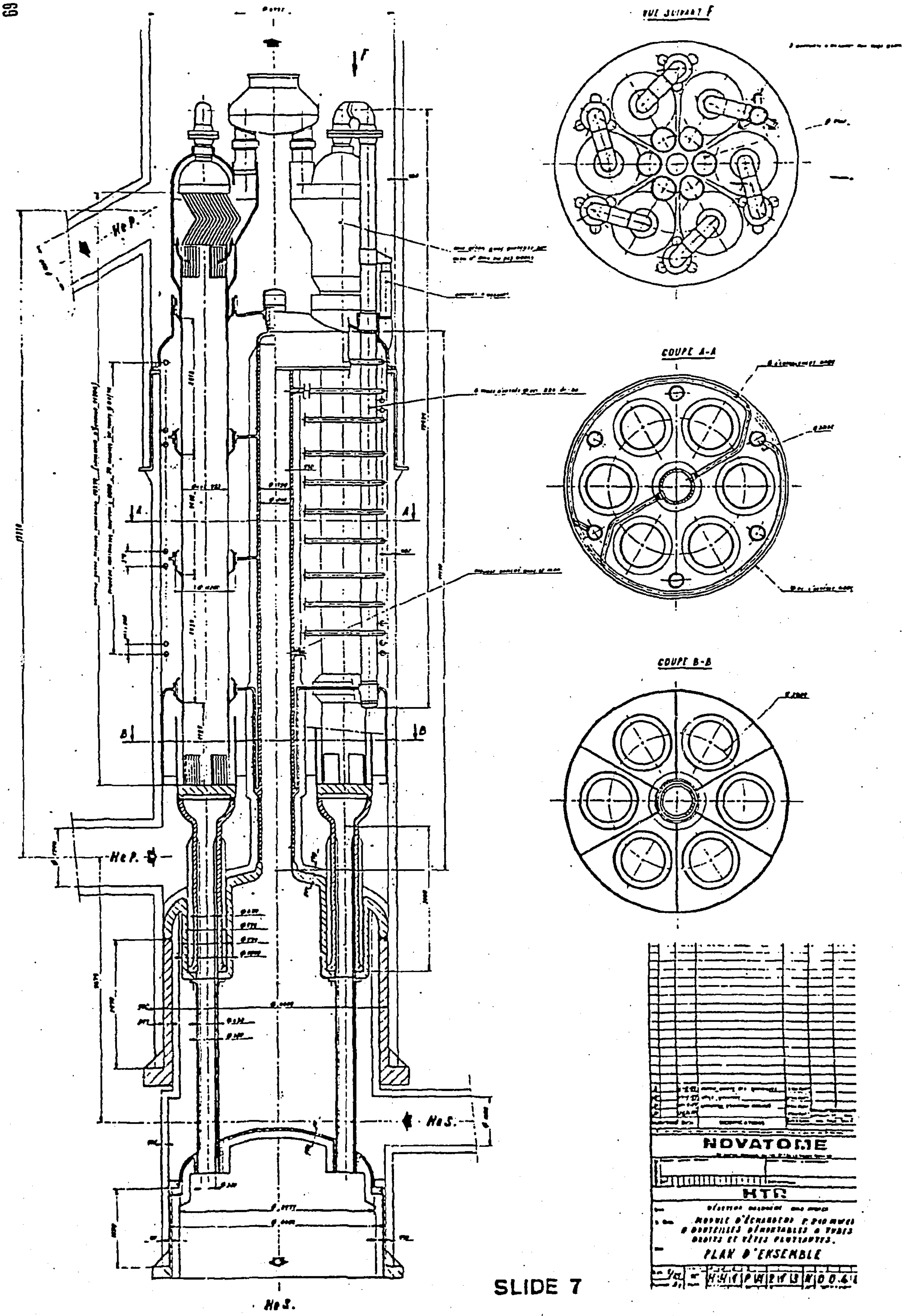
MODULE CHARACTERISTICS

| | | |
|---|---|---|
| – Tube diameter | | 10/14 mm |
| – Triangular pitch | | 21 mm |
| – Number of tubes | | 1 602 |
| – Heat exchange length | | 10 m |
| – Front area | prim. 0,486 m$^2$ | inter. 0,126 m$^2$ |
| – Heat exchange area | | 711 m$^2$ |
| – Flow velocity inside tubes | | 29 m/s |
| – Flow velocity outside tubes | | 14 m/s |
| – Pressure drop inside the bundle | | 460 mbar |
| – Pressure drop outside the bundle | | 40 mbar |
| – Diameter | | 940 mm |
| – Weight of the exchange bundle | | 9,75 t |
| – Total weight | | 24,7 t |

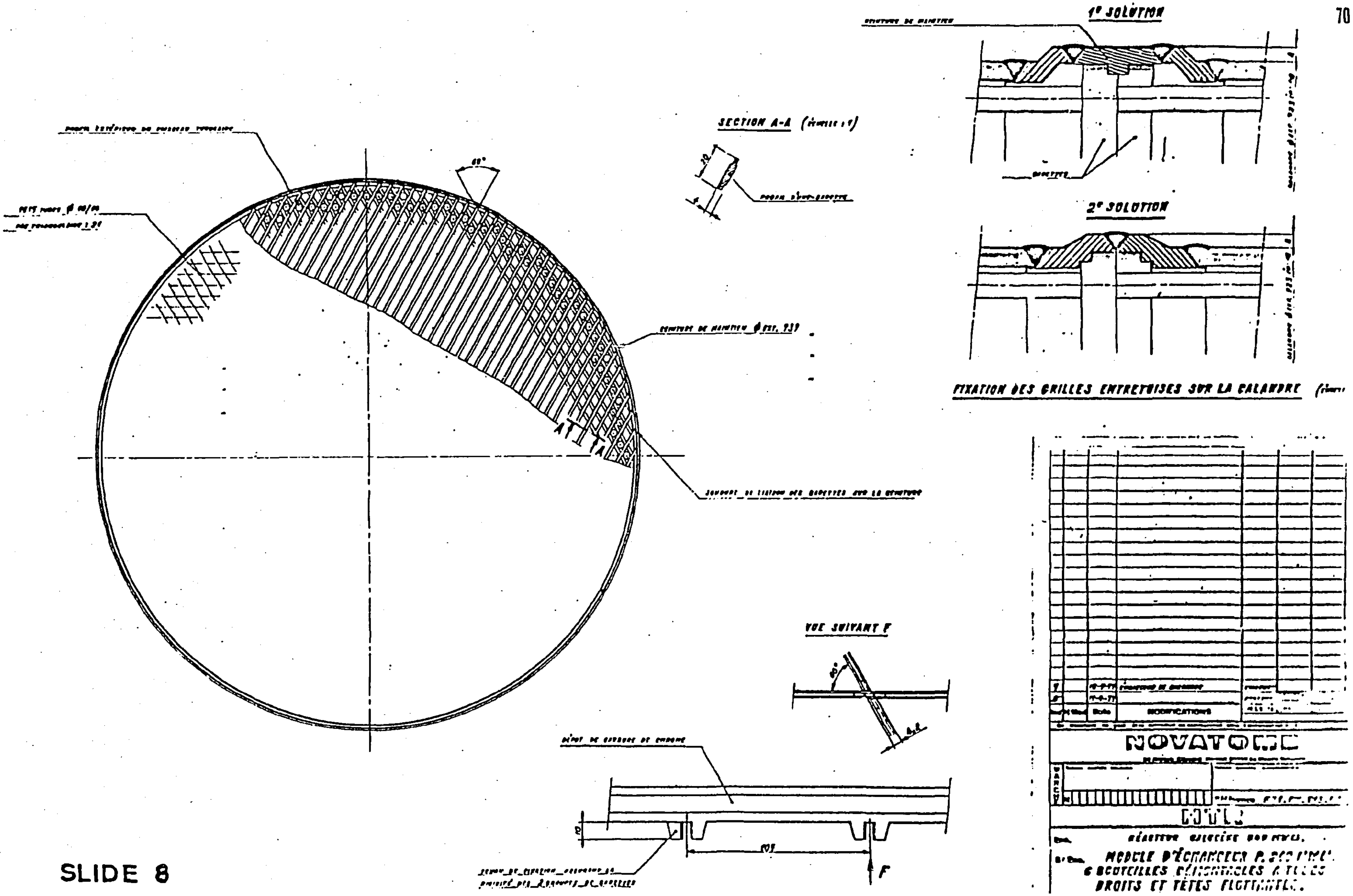
SLIDE 5



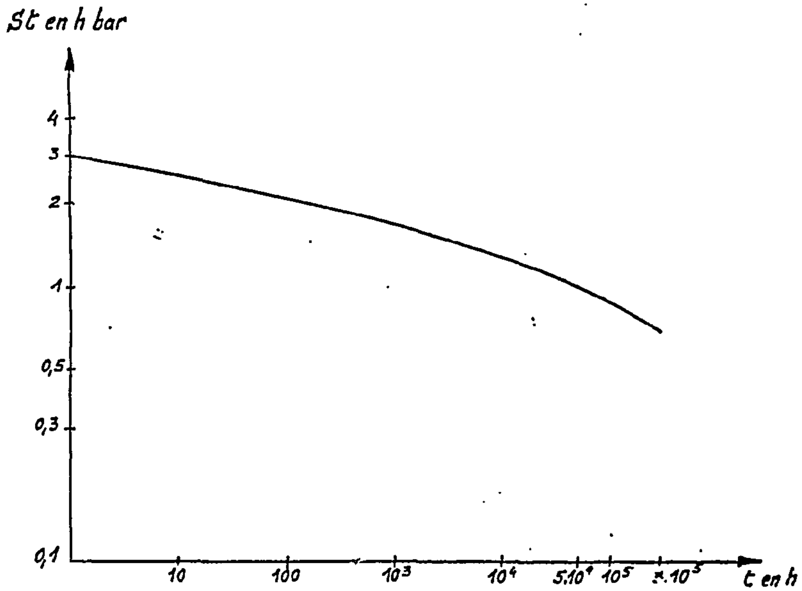

SLIDE 6


VUE SUIVANT F
COUPE A-A
COUPE B-B
He P.
He P.
He S.
He S.
A
A
B
B
NOVATOME
HTR
PLAN D'ENSEMBLE

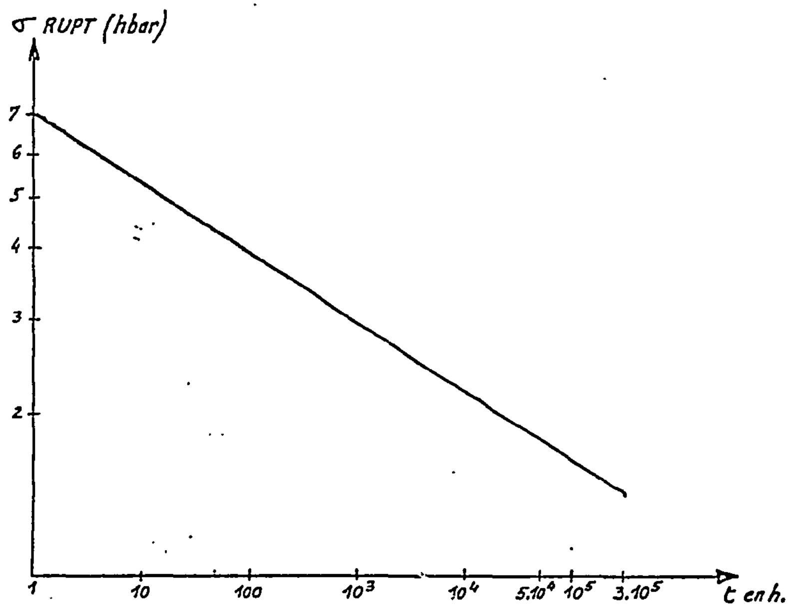
SLIDE 7


1re SOLUTION
2e SOLUTION
SECTION A-A
FIXATION DES GRILLES ENTRETOISES SUR LA CALANDRE
VUE SUIVANT F
F
MODIFICATIONS
NOVATOME

SLIDE 8




SLIDE 9




SLIDE 10



# HEAT-EXCHANGING COMPONENTS FOR COAL GASIFICATION:

## – HE/HE INTERMEDIATE HEAT EXCHANGER (IHX) AND STEAM REFORMER (STR) IN THE PRIMARY CIRCUIT

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### Constructive design and helium flow of the IHX

As compared with the conventional manufacture of apparatus , there are some essential differences due to the

- utilization of 950°C hot helium from a HTR
- installation in a PCRV
- prevention of major failures
- long lifetime

The following basic solutions result from these essential features:

- Metallic tubular heat exchanger with extremely high wall temperatures
- Precautionary measures (in-service inspections)
- Fully qualified material
- Comprehensive analyses of the strength and creep behaviour
- Comprehensive qualification tests of the component