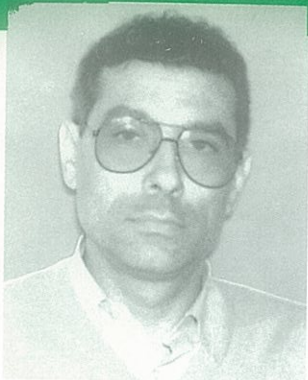
PROGRAM TO IMPROVE REACTOR CAPACITY IN BOILING WATER REACTORS

F. ALCANTUD - F. CASTRILLO - J. SERRA



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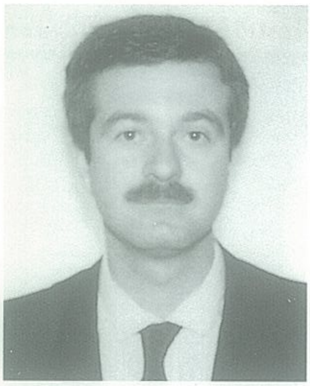

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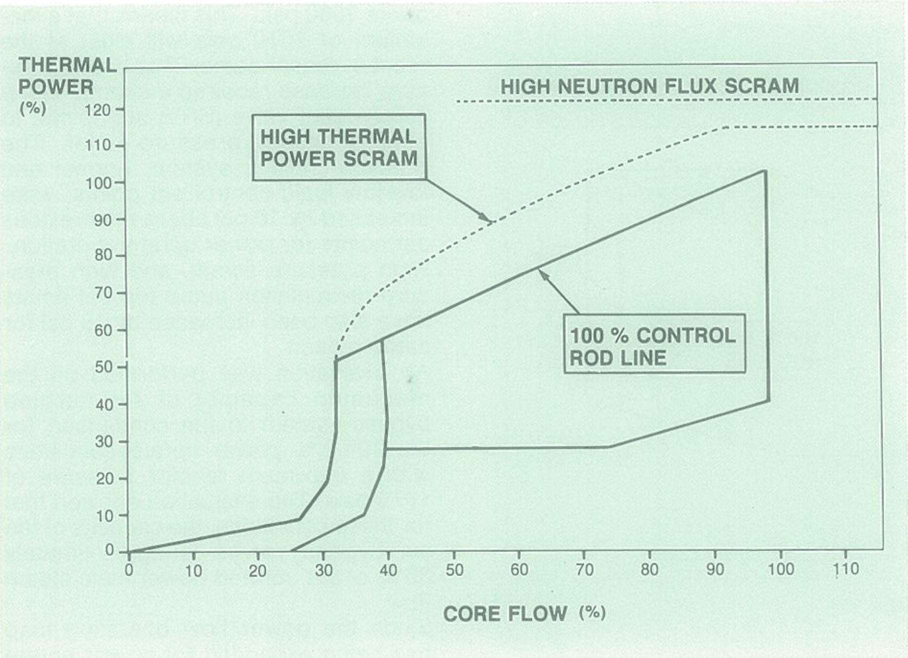
Cumulative experience in BWR plants, design efforts of NSSS suppliers and oversizing of systems and equipment have led to definition of several economically attractive operating options and strategies, for the purpose of increasing and improving cycle length, operating power, cycle efficiency, load capacity factor, plant availability and operation plant flexibility.

The following operating options are among those avaliable for BWR's:

- MEOD (Maximum Extended Operating Domain), that allows operation in two additional zones of the operating map: the Extended Load Line (ELL) region, above the 100 % rod line, and the Increased Core Flow region (ICF), with core flows higher than rated (see Figure II).
- FWHOS (Feed Water Heater Out of Service), allows long term operation with one FW heater of service at a power level determined by analysis.
- SLO (Single Loop Operation) for continuous operation with only one Recirculation loop in service.
- FFWTR (Final Feed Water Temperature Reduction) allows a gradual reduction of Feedwater tempeature at the end of cycle to increase core reactivity.
- PU (Power Uprate) allows operation at a higher than rated power level.
- Spectral Shift: by operating at low flow conditions the increased void content of the core makes the neutron spectrum "harder", which allows plutonium generation to be burned in the later period of the cycle.
- Burnup Increase: leads to longer cycles by increasing fuel enrichment and/or using advanced design fuel elements which withstand higer burnup.

PROGRAM TO IMPROVE REACTOR CAPACITY IN COFRENTES NPP

Knowing the existing margins in the Cofrentes NSS and BOP design, Hi-



FI *CN Cofrentes. Operating map (original).*

droeléctrica Española decided to initiate a program to improve reactor capacity, to be implemented in two stages, with the objective of making them operatives in cycles 4 and 5 respectively.

After a detailed study, in which the different options described above were analized, it was decided to initiate the first stage of the program by licensing the following alternatives:

- Extension of operating map (MEOD).
- Power uprate (PU) to 102 %.

This choice was based on the importance of plant economy and operating flexibility, the readiness for improvements implementation, and positive experience in other plants where these options are in operation.

In October 1986 a technical proposal for the program was presented to the Consejo de Seguridad Nuclear. Safety and licensing calculations and analysis were initiated in January 1987, with a duration of six months. A generic preliminary descriptive report was issued in February 1987 and presented to the MINER (Dirección Provincial de Valencia). In September 1987, the specific Safety Analysis Report was presented to the Administration, and the Provisional Permit for Operation was officially published in March 1988, a few days before the beginning of Cycle 4 operation.

Figure I shows the Cofrentes operating map before MEOD + PU implementation. Figure II shows the maximum extended map based on design systems capabilities, and Figure III shows the Cofrentes licensed map, in operation since the beginning of Cycle 4.

As illustrated in Figure II, MEOD provides a high flexibility for operation and improves plant capacity factor, in both of the extended regions (ELLR and ICFR).

The ELLR is limited to a 80 % core flow, at 102 % thermal power, and by the 120 % rod-line, this boundary was determined by General Electric as the highest rod-line operationally feasible in meeting thermal and reactivity margins.

The ICFR was determined for the maximum capacity of the Recirculation system for the full open position of the flow control valve (108 % core flow at 102 % power) and further limited to a maximum core flow of 105 % due to internal vibration considerations.

The ELLR allows power ascension with rod-lines higher than the original upper limit of 105 %, and provides a margin to withdraw control rods and accelerate power increase: it also gives a wide range of core flow, supplemented by that of the ICFR, to compensate core reactivity to keep full power operation, which is specially interesting at EOC conditions with all rods out.

Power Uprate (PU) feasibility studies carried out for Cofrentes indicated that the plant can be operated in a continuous and safe mode at 104.2 % thermal power (approximately 105 % electrical output). It was decided to implement this capability in two stages; the first step includes MEOD and a 2 % PU, the second one will consider a PU up to 104.2 % thermal power, with confidence and experience gained during operation at increased power.

The main difference in the number of analyses required to justify operation to 102 % or 104.2 %, is that current FSAR calculations of ECCS performance are done at 104.2 % thermal power that covers the 2 % margin requied for licensing 102 % PU. However increasing thermal power to 104.2 % will require a complete analysis of ECCS performance at a power level of 1.02 * 104.2 %.

ANALYSIS PERFORMED FOR MEOD + PU IMPLEMENTATION

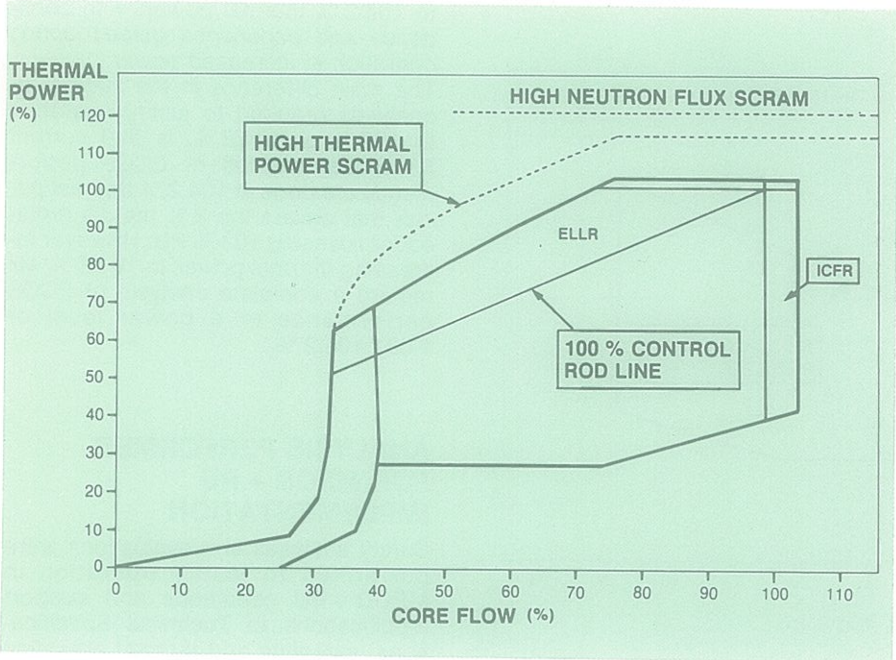
Safety analyses and evaluations were performed to justify operation in MEOD + PU conditions and support modifications to Technical Specifications, setpoints and thermal operating limits. These analyses included reevaluation of NSSS and BOP with specific calculations in the areas of abnormal transients, containment accident response, internal vessel structures and ECCS performance (impact of MEOD on early boiling transition only), and were reported in an Appendix to the Cofrentes FSAR.

Calculations were performed by General Electric for transients with FFWTR conditions, mechanical and vibrations of vessel internals and ECCS performance, etc. ENUSA made heat balances, Recirculation system performance and transient analysis under maximum power. Empresarios Agrupados (Architect-Engineer during plant construction) performed BOP evaluations and thermomechanical system calculations. All calculations required for MEOD + PU (102 %) were performed at conditions that cover future operation at PU (104.2 %). A brief description of systems capacity verification and safety analyses performed is described below.

SYSTEM CAPACITY VERIFICATION

Impact of MEOD and Power Uprate in both, Nuclear Steam Supply and Balance of Plant systems and equipment were evaluated. The evaluations included plant auxiliary systems, plant piping stress analysis, irradiated vessel fracture toughness evaluations, and pressure differences and vibrations in vessel internals.

The reactor internal pressure difference analysis was performed at the most limiting conditions of the extended map boundary, at 106.3 % Power, 108 % flow and 40 % Power, 114 % flow. The objective of the evaluations was to de-



FII *CN Cofrentes. Extended operating map.*

termine the maximum pressure differentials across the various components during normal steady-state, upset, emergency and faulted conditions, and compare them with previous licensing analyses performed for BWR/6-218 plants. The mechanical evaluation of reactor internals included a stress verifications of jet pumps, core plate, top guide, steam separator and dryers, core shoud, control rod guide tube, control rod drive housing, core spray line, core spray sparger, incore housing, incore guide tube, orificed fuel support, etc., concluding that the loading conditions associated with an uprate of up to 104.2 % power in the MEOD boundary was within the design capability of the RPV components and the internal hardware.

An evaluation of the vibration response of the reactor internals, for a range of core flows and power up to the new maximum core flow of 114 % rated and maximum thermal power of 104.2 % rated, was performed. The analyses were semi-empirical, relying mainly on the start-up vibration measurements of the Kuosheng-1 reactor that is identical in size and internal design to the Cofrentes reactor. It was concluded that the reactor can operate within these new limits without causing unacceptable vibrations that would result in fatigure failures of the internal reactor components.

Fuel support loads and fuel assembly lift were evaluated, concluding that fuel assembly lift at the limiting faulted condition is a small fraction of the applicable design criteria.

An evaluation of the reactor recirculation system was performed to determinate the maximum core flow capability, concluding that the maximum achievable core flow capability is approximately 108 % of rated for operation at 104.2 % rated power, and with the recirculation flow control valve fully opened.

As core power decreases with constant FCU position the maximum core flow capability increases due to a decrease of the two phase friction factor multipliers as a result of the decrease in the core void fraction. A maximum core flow of 114 % of rated can be achieved at 40 % rated power. This point is the right-down corner of the maximum extended operating map, as can be seen in figure III (point C). It was concluded that the map extension and power uprate would be well within the capability of the recirculation system.

Main steam line and turbine control valve (TCV) capacity to accomodate a 5 % increase in the turbine steam flow were evaluated. The conclusion was that TCV'S have a sufficient control margin, slightly increasing the regulator set-point to avoid operation with TCV'S at the upper end of their position that would produce greater travels when responding to small variations in steam flow, and the consequent loss of regulation capacity. Therefore, in order to limit duty on the TCV'S, as well as to achieve good TCV operating characteristics, and to obtain suitable control margin in the TCV'S at uprated power, it was decided to increase the operating reactor dome pressure by 10 psi abore 1060 psia. This means that a maximum of 1070 psia will exist at the reactor vessel dome. This dome pressure increase required a change in the safety-relief valve (SRV) set-points, to ensure proper pressure relief. The pressure relieve system, normal and low-low logic control set points, were increased by 10 psi abore the previous set points for power uprate operation. High pressure scram, and high pressure recirculation pump trip set-points have also been increased by 10 psi for same reason.

An evaluation was performed on the maximum capacity of the turbine bypass system to the condenser, for the 104.2 % power uprate conditions with a maximum reactor pressure of 1070 psia. The evaluation showed that for these conditions, the capacity of the six bypass valves is approximately 35 % of the uprated power main steam flow.

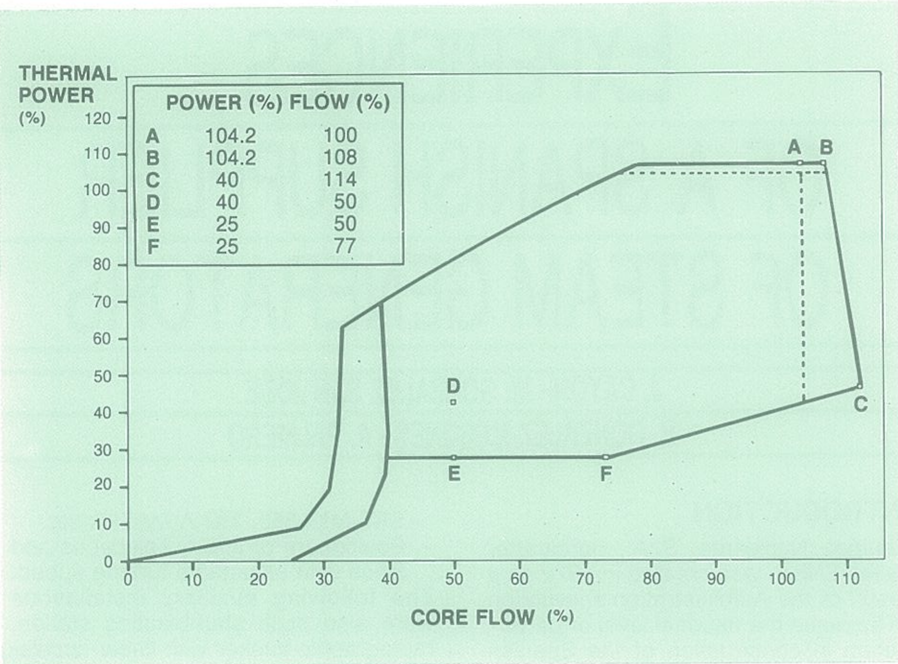
Since the power flow operating map has being expanded for power uprate and MEOD operation, the flow biased APRM rod block and simulated thermal power scram needed to be changed.

Other evaluated systems were:

- Residual Heat Removal System (RHRS).
- High Pressure Injection System.
- Standby Liquid Control System (SBLCS).
- Condensate System and Feedwater System.
- Reactor Water Clean-up System.
- Control Rod Drive Hydraulic System.
- Primary System Piping Stress Analysis.
- Closed Cooling Water System.
- Fuel Pool Cooling and Clean-up System.
- Turbine Island-Plant Electric System (Turbine-Generator, 20 KV Isolated Phase Bus Ducts, Main Transformer, Auxiliary Transformers, 6.3 KV Non-Segregated Buses).
- Reactor Pressure Vessel (fluence, fracture toughness analysis).
- Essential Service Water and Ultimate Heat Sink.
- Condensate Demineralizers.
- Steam Jet Air Ejectors.
- Condenser and Circulation Water.
- Heationg, Ventilation and Airconditioning.
- Pressurization of Subcompartments.
- Offgas System and Hydrogen Recombiners.
- Radiological Analysis.
- Thermal Balances.
- Stability Analysis.

SAFETY ANALYSIS

All Abnormal Operating transients described in SAR chapter 15 were review-



FIII *CN Cofrentes. Transient Analysis Initial Conditions.*

ed for the uprated power with MEOD conditions. An initial power or 3015 MWth was used (104.2 % rated power as in the original SAR analysis). The core flow conditions chosen for the analysis were 100 % of rated and 108 % of rated (this conditions bounds the lower flow situations) as allowable by MEOD. Plant heat balances, core coolant hydraulic and nuclear transient parameter data, based on the end of 18 month equilibrium cycle were used in the transient analysis.

The analysis results showed that thermal limits were penalized for increased core flow region (1.21 versus 1.18 of minimum critical power ratio for the limiting transient at increased and nominal flow conditions). If credit for the real control rod insertion speed is taken, the current MCPR operating limit of 1.18 conservatively bounds both rated and increased core flow operation, so General Electric Co. option B limits (Reference 4) for MCPR can be used for increased core flow operation.

Low power/flow transient analyses were performed to verify results and trends with generic analysis and for develop connections to MCPR and MAPLHGR when operating at conditions other than nominal.

The original SAR, Emergency Core Cooling System Performance analyses were performed at 104.2 % of the rated power level and 100 % rated flow, covering the 102 % uprate with the 2 % margin required by Regulatory guides (Reference 2). However, it was necessary to verify compliance with the design criteria for operating with MEOD option. The limiting condition for the peak cladding Temperature was found to be at minimum flow and maximum power control rod line (upper left corner of the operating map) because this initial condition increases the probability of losing nucleate boiling at the highest power axial node prior to the time of jet pump recovery. This phenomenon is called early boiling transition and could affect the calculated peak cladding temperature.

The compliance with design criteria was based on generic analysis results, and verified with Cofrentes specific analysis performed at 106.3 % power covering a future operating power increase to 104.2 % of rated.

The containment long and short term response was reviewed to determine the effects of Cofrentes operation at the power uprate condition. The limiting break for short term response is a double-ended guillotine break of a recirculation line at 62 % rated power and 32 % rated core flow with reduced feed water temperature. This corresponds to the point of maximum subcooling at vessel downcomer region in the power/flow map.

As part of the long term peak suppression pool temperature analysis, two conservatisms in the original FSAR analysis were identified and suppressed:

- The decay heat model (ANSI/ANS-5,1 1979 versus the ANS-5 standard 1973).
- Credit to the Containment structures as heat sinks was taken.

All the safety analyses performed have been documented in Appendix 15C to the FSAR, that also include thermal balances, system evaluations, radiological analysis and instrument set point changes.

CONFIRMATORY TESTING

Two set of tests were programmed to verify the correct behavior of the Cofrentes reactor under the new operating conditions. The first one corresponds to the themal hydraulic stability; checking that system response to a perturbation is not oscillatory. The test consisted of the introduction of one two notches of a control rod, which produces an important variation of local neutron flux, measured in the nearest LPRM. Data of LPRM and APRM were registered and dumped response was verified. The test were performed at 50 % flow and maximum power, at 102 % and power minimum core flow, and at 102 % power with maximum core flow.

The purpose of the second set of tests was to obtain recirculation system performance data during operation at the maximum power line, and in the maximun flow and power region (ICF).

FINAL CONSIDERATIONS

Cycle 4 is currently operating successfully under MEOD + PU (102 %) conditions. Maximum core flow (FCV fully opened) attained at maximum power was slightly lower than 105 % of rated. In July/88, Safety analyses and calculations were initiated to justify operation at a maximum thermal power of 104.2 % (3015 MWth). In October/88 the corresponding Licensing Report was presented to the Consejo de Seguridad Nuclear and official approval is expected before startup of Cycle 5.

Calculations to justify operation with one Recirculation loop out of service (the SLO) have been completed, and Safety Analysis Report is being prepared.
tion.

REFERENCES

(1) Regulatory Guide 1.49, *Power Levels of Nuclear Power Plants.*
(2) Title 10, Chapter 1, Code of Federal Regulations, Part 50, Apendix K.
(3) Appendix 15C to the Cofrentes FSAR.
(4) GESSAR II General Electric Standard Safety Analysis Report.

EXPERIENCES OF A SPANISH SUPPLIER OF STEAM GENERATORS

J. CAYON - M. GONZALEZ SAN JOSE
E. GONZALEZ-MESONES - A. PALMERO

INTRODUCTION

Equipos Nucleares, S. A., hereinafter called ENSA, was created in 1972 as a result of the Administration's invitation to increase the national level of participation in construction of the Spanish Nuclear Power Plants Program. As a result, ENSA was conceived to undertake the manufacture of the main primary circuit components: Reactor pressure vessels, steam generators, pressurizers, core structures and primary piping.

From the very beginning, we were conscious of the different technologies involved in the Spanish nuclear program and we established the required capacities to satisfy market demands.

Such a technological diversification has allowed us to become an unique case in the world, as we have had the opportunity to work with technologies from Westinghouse, KWU, General Electric and other customers who have helped us "to understand" several techniques and to reach the highest technological level.

MAIN FACILITIES

To undertake the above mentioned manufacturing program, ENSA was designed with facilities not commonly found in the domestic market. A summary of such facilities is shown below:

- Three bays with a total surface area of 18,000 m^2 and handling capacity of 225 t, 325 t and 900 t, respectively.
- Schiess vertical boring machine with 7 m diameter (maximum of 12 m) and a maximum weight of 250 t.
- INNSE machining center with two milling machines with mobile heads & columns. Rotation table and internal tower with numerical control.
- Deep drilling machines (2) Deepmatic type, with n.c. and three spindles with capacity to drill one meter.
- Welding equipment: Safex, C3, C2, TIG, CT-300, plasma, AGA-GAS, SAF-MIG-355, TIG A MATIC, etc.
- Positioners of 250 t, Teledynes and Bode with adjustable turning speed.

The following auxiliary installations were also built: shut-blasting station, radiographic bunker with linear accelerator, heat treatment furnace for pieces up to 17 m long, 12 m hydraulic pit, mechanical shop with lathes and milling machines with n.c., etc.

ENSA's organization was designed with special care insofar as its capacities in the engineering and quality assurance areas. Knowledge of the ASME Code, TUV requirements and Customer specifications was given special attention.

A complete Welding laboratory with Metrology, Metallographic, Chemical and Non-Destructive equipment and capacities was included.

MAIN STEAM GENERATOR CHARACTERISTICS

We consider the Steam Generators to be the components requiring a maximum number of manufacturing techniques. Therefore, we will concentrate our article on the main steps involved in manufacturing S.G.'s.

We will start by describing the different steam generators that have partially or totally been manufactured at the ENSA shop:

- Three models "E-2" Westinghouse type for Sayago Site.
- Three models "F" Westinghouse type for Vandellos Site.
- One model "D" Westinghouse type for Lemoniz Site.
- Six models "54CT" KWU type (with preheaters) for Trillo Site.
- Four KWU type (without preheaters) for Konvoi project.

Table I shows the main characteristics of the steam generators, describing the different manufacturing processes used for each one.

This paper was prepared by Joaquín CAYON and Manuel GONZALEZ, Steam Generator Design Engineers, by Eduardo GONZALEZ-MESONES, head of the Engineering Division, and by Angel PALMERO, head of the Technology Division, all employees of ENSA.

T I
Main steam generator data

Data/Site	Trillo-I/II	Konvoi (1)	CN Sayago (2)	CN Vandellos
Design	KWU	KWU	Westinghouse	Westinghouse
Type	Vert-Haz U-tube	Vert-Haz U-tube	Vert-Haz U-tube	Vert-Haz U-tube
Power	1009 Mw	1300 Mw	900 Mw	900 Mw
No. of TIES	3	4	3	3
Pressure/temp. design				
– Primary	178,5 kg/cm^2 350 °C	–	174 kg/cm^{2-} 343 °C	174 kg/cm^{2-} 343 °C
– Secundary	89 kg/cm^2 350 °C	–	90 kg/cm^{2-} 316 °C	83 kg/cm^{2-} 316 °C
Weight	440 t	–	413 t	313 t
Total length	21.500 mm	5.540 mm	22.000 mm	20.600 mm
Upper part diam.	4.610 mm	–	5.040 mm	4.476 mm
Lower part diam.	3.700 mm	3.667 mm	3.768 mm	3.454 mm
Max. wall thickness	135 mm	155 mm	114 mm	130 mm
Tube sheet thick.	700 mm	700 mm	–	534 mm
Number of U tubes	4.000		–	5.626
Tube dimensions	Ø 22 x 1,2	–	–	Ø 17,32 x 0,91
Preheater	Sí	No	Sí	No
Feedwater in.	Upper+Power level (Aux. & emerg.)	Upper level	Upper level	Upper level
Materials:				
Shells	20MnMoNi55 (Laminated)	20MnMoNi55	SA-533Gr.A Cl.2	SA-533 Gr. A Cl.2
Upper bottom	Laminated " (Conformed)	–	" Gr.B	"
Lower bottom	" (Conformed)	–	" Gr.B	SA-216 Gr. wcc (cast.)
Tube sheet	" (Wrought)	20MnMoNi55 (Wrought)	–	SA-508 Cl.2a (Wrought)
Nozzles	"	"	SA-508 Cl.2a	SA-508 Cl.2a (Wrought)
Tube bundle	Incoloy 800	–	–	SA-166
Baffles	1.4541 (DIN 17440)	–	–	SA-240 Tp-304
Processes:				
Rottom Cladding	SAW Banda+SMAW Austenitic Stainless	–	SAW-Banda aus.	SAW-Banda aus.
Tube sheet cladding	SAW Banda+SMAW	SAW Banda+SMAW with Inconel 600	–	MIG with wire
Tube-Tube sheet weld.	TIG aut. pressing (with wire)	–	TIG without wire	TIG without wire
Tube expansion	2 zones (primary & secondary) Mechanical step	–	Hydraulic	Hydraulic
Tests:				
Superficial NDE	Liquid penetrant Magnetic Particle	Liquid penetrant Magnetic Particle	Liquid Penetrant Magnetic Particle	Liquid Particle Magnetic Particle
Volumetric NDE	Ultrasound Radiography	Ultrasound Radiography	Ultrasound Radiography	Ultrasound Radiography
Hydrostest:				
– Primary	233 kg/cm^2	–	217 kg/cm^2	217 kg/cm^2
– Secundary	116,7 kg/cm^2	–	112 kg/cm^2	103 kg/cm^2
Helium test	Yes (max. allowable leak) 1 x 10^{-7} std. cc./sec.)	–	Yes	Yes
Extens. measures	No	–	No	No

Notes:
(1) ENSA only manufactured the tube-sheet subassembly and upper shell, including tube-sheet drilling.
(2) ENSA did not manufacture upper port of S.G.

SPECIAL PROCESSES

ENSA has developed and qualified several processes to manufacture the referenced S.G.'s. The main processes are described hereinbelow:

- Automatic welding for butt-welding (SAW).
- Automatic cladding for austenitic cladding with strip.
- Automatic tube-tube sheet welding.
- Automatic TIG with inconel wire.
- Automatic TIG without wire.
- Cladding of tube-sheet:
  - automatic SAW with inconel strip on tube-sheet
  - automatic MIG with inconel wire on tube-sheet
- Tube expansion procedures:
  - mechanical
  - mechanical-hydraulic
  - hydraulic
- Tube sheet deep drilling (up to 700 mm) processes.
  - Helium, Bubble and Hydrostatic Tests.
  - Extensiometric measurements with extensiometric gauges.
  - Nondestructive techniques.

MAIN MANUFACTURING STEPS

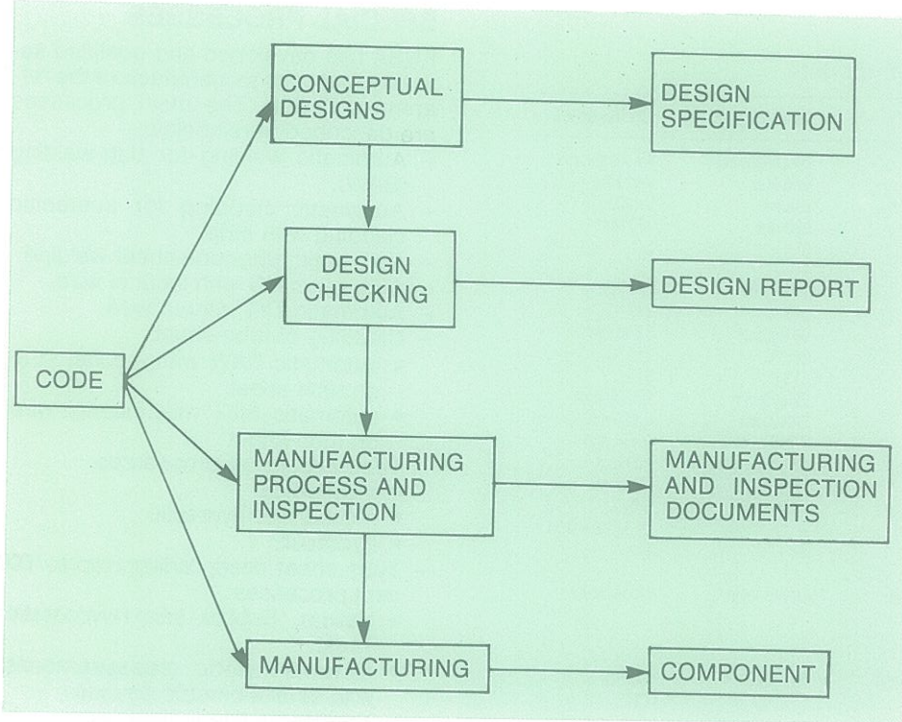
Processes used during manufacture of the intermediate section of the S.G. are the most critical ones. We describe some of them that are performed inside a special area identified as the "clean area", where special cleanliness and control requirements are in force.

DIAPHRAGM ASSEMBLY AND ALIGNMENT

The construction, pre-assembly of packages and installation of diaphragms are complex and difficult operations but essential to obtain a proper alignment and tubing.

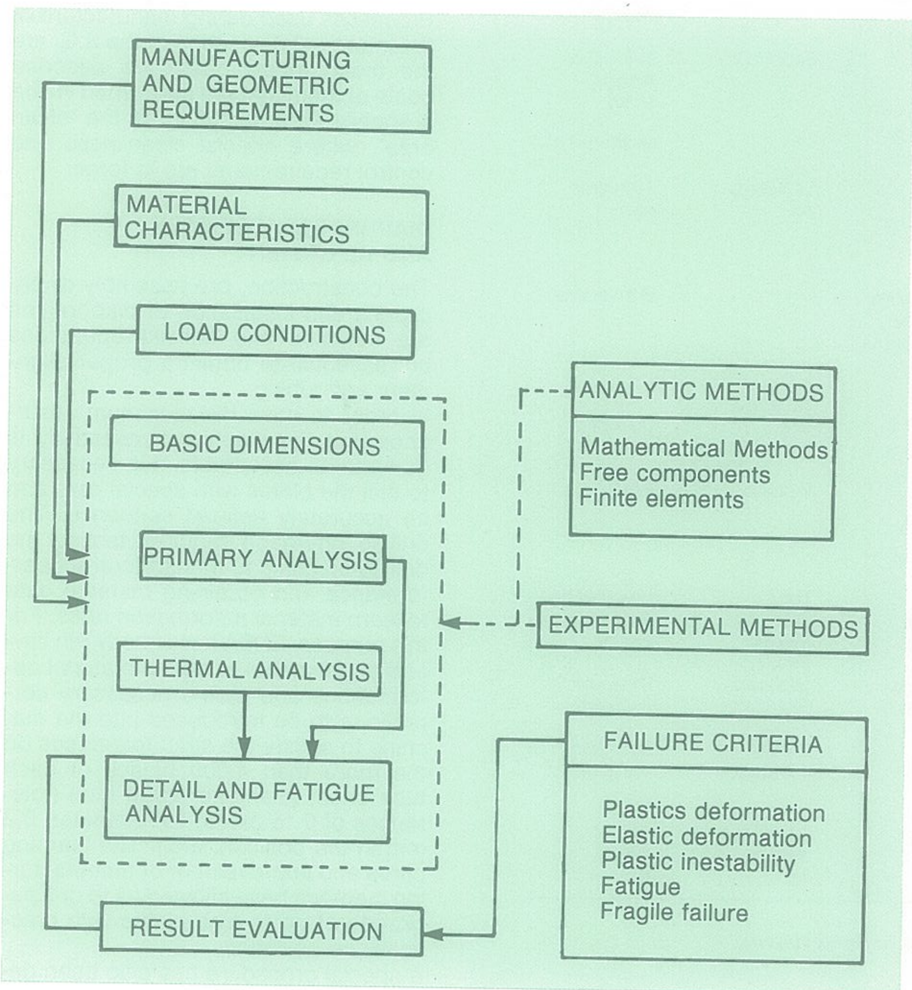
In order to have the maximum assurance that the diaphragm assembly is going to be acceptable, it is necessary to drill the plates with special care and an accurately defined sequence. The drilling operation requires testing the drilling machine to monitor correct performance and obtaining material data to learn material deformation rates. For this purpose, ENSA has already run several experiments to obtain material deformations and define necessary corrections to be introduced into the machine to satisfy the strict tolerances on the more than 4.000 holecs of each tube sheet (diameter 3.000 mm) (tolerances of 0.15 mm to the diameter, 0,2 mm in the position, etc.). The learning curve and improvement of manufacturing methods have allowed us to drill packages of up to nine plates with practically no deviation.

A special procedure has also been de-



F I *Design and manufacture of a steam generator*

F II *Analysis justification*



veloped to process the data from control equipment (optical alignment telescopes) through a computer program and provide the necessary modifications to optimize the alignment.

The above performance and a detailed and conscious dimensional control of the structuring of grids, tie-rods, separator tubes, etc. will assure an adequate tubing operation.

TUBE-TUBE SHEET WELDING

Experience shows that the tube-tube sheet weld is the most critical point of the steam generator. Any of the thousands of identical welds have to assure the integrity of the generator. The individual welds are required to show "no indication" under liquid penetrant test, and leakages between $1\times 10^{-6}/1 \times 10^{-7}$ std.cc/sec. when subjected to the helium leak test.

To obtain such a quality, ENSA has qualified several tube-welding and tube-expansion procedures which are shown in Table I. It has also been necessary to homologate equipment and operators, and any modifications of parameters and/or equipment have also been homologated.

Further to the requirements described above, it is necessary to perform a thorough and detailed follow-up of the operations, shift by shift and operator by operator. At the beginning of each shift, coupons with identical requirements as for the steam generator have to be manufactured and tested daily to monitor that quality established during qualifications is maintained during manufacturing performance.

DESIGN JUSTIFICATION

ENSA has run stress calculations on all components of the primary circuit of steam generators. However for purposes of this article, we believe it is advisable to describe the calculation process we have followed.

The mechanical design of the S.G. is based on the stress analysis justification concept. This concept is defined in design standards such as ASME Code and KTA rules. Following this philosophy, the design study of the S.G. is performed in the following steps:

- Design and operational condition definition.
- Material selection.
- Stress design justification.
- Document preparation for manufacturing, testing and opeation of S.G.'s.

The complete sequence is shown in Table I.

On customer requirement, ENSA is responsible for monitoring the mechanical design, according to the standards, codes and requirements applicable on

Continued on page 43