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DEVELOPMENTS IN CANDU FUEL TECHNOLOGY IN ARGENTINA

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ABSTRACT

This presentation updates the paper presented at the Heavy Water Reactor Fuel Technology Seminar held in Bariloche, Argentina, in 1983. Main efforts in the last two years were devoted to reach production scale level and in-reactor fuel performance qualification. Different aspects and results of these stages are reported. Some activities such as processes and production equipment optimization are discussed. An optimization of in-reactor fuel performance prediction tool (BACO Code) was also made. A short description of the work strategy faced in order to detect and confirm the causes of fuel failure and a brief summary of the reached results is presented.

1. INTRODUCTION

Since 1957, Argentina has been developing the necessary capability to design, develop and produce both research and power reactor fuel.

In 1978, four years after signing the contract for the second Power Station -of Candu type- we started the necessary works for the development of our own capability in Pressure Tube Reactor Fuel Technology.

The evolution of this work was presented in the International Seminar on Heavy Water Reactor Fuel Technology held in Bariloche, Argentina, in June 1983. (1)

This paper is aimed at the subsequent work done, especially on production scale and in-reactor performance.

The Embalse Power Station of CANDU 600 MWe type has been in operation since May 1983. Its power history is shown in Fig. 1.

Aroung 14.000 fuel bundles from Canadian manufacture are until now being irradiated or loaded in the reactor.

Five hundred and twenty-four bundles manufactured in the country are being loaded or irradiated.

Full domestic supply is foreseen to be reached in the next two years.

2. FUNDAMENTAL WORK

The development of processes and the design and fuel behaviour conditions promoted some fundamental works needed for supporting the technology knowledge.

In the field of in-reactor fuel rod and its material behaviour we have adjusted the BACO Code as a tool for power cycling operation.(2)

The BACO Code, developed at CNEA, is the standard tool for design and performance analysis of fuel rods. Its capability for simulation of Candu rods is shown in Table 1, where Code predictions and experimental measurements are compared for 8 rods irradiated at high power in the NRX reactor.

The BACO Code is currently used for the analysis of load-following operation of the Embalse Nuclear Power Station; the Code potentiality for load-following analysis has been shown elsewhere (7).

Bearing pad and spacers brazing and end cap resistance welding are the most important processes which introduce relevant metallurgical changes in cladding tubes. For those reasosn, we have faced several fundamental works to correlate mechanical and corrosion properties with those of as fabricated tubes (3, 4, 5, 6).

Table 2 summarizes the studies and the main goal reached with them

3. DEVELOPMENT CAPABILITY

In order to know the most important parameters relevant for the production it was necessary to develop several process studies which would allow us to build a supporting structure.

This laboratories are now being used for the improvement and optimization of production processes and for the development of other reactors fuel.

Moreover, we have developed a modular concept for laboratory or pilot scale plant which may be used by other countries entering in power reactor fuel technology.

As we have earlier reported, the development of production equipment was very important for us and we have concluded with reliable equipment for production.

4. PRODUCTION

The manufacturing line started operation during the last quarter of 1983.

From the first series of 50 fuel bundles, thirty six were loaded in reactor in 1984 under CNEA responsibility, since all risks arising from the introduction of domestic fuel during the reactor warranty period had to be undertaken.

In 1984, 500 fuel bundles were manufactured. This was the beginning of the first mass production state for attending the program for progressive loading of domestic fuel bundles into the reactor.

This program included, besides the first 36 fuel bundles, the loading of 16 additional channels once the reshuffling operations in the first three had taken place. Later on, 120 channels should be added.

Since February 1985 and until the last quarter of that year, about 600 fuel bundles were manufactured, but production was discontinued because of end caps welding malfunction confirmed by the rapid increase of in-reactor fuel failure.

After a deep corrective maintenance and important modifications in the end cap welding operation, production was re-started at the end of 1985.

From then onwards, it was decided to go on producing with a low but sustained rhythm until the post-irradiation program and the re-starting of the irradiation program confirm that the causes of failures have in fact been removed.

Fig. 2 presents the production histogram and its projection until the end of 1986.

The irradiation program, discontinued after the third quarter of 1985,went on with the loading of four channels (32 fuel bundles) last January.

After these four channels reshuffling operation, the program shall go on with the loading of 16 channels and afterwards with thirty more. With the reshuffling operations in these last channels, the mass loading of domestic fuel in the reactor shall be accomplished for the end of next year.

The series of fuel bundles already manufactured have allowed the evaluation and proof of the quality and production capacity of the processes and equipment developed in our country. Due to this evaluation, additional units were incorporated to most stages of the line, especially to that of special processes, in order to reach the production volumes necessary to fulfill the local needs of fuel bundles supply.

These additional units are already in operation, except for the end caps welding stage, for which another automatic machine is being constructed.

Consequently, it is foreseen that the line shall be ready to meet mass production from the beginning of next year.

5. PERFORMANCE

After Power Station contractual provisional acceptance, the loading of fuel in the reactor was started. Thirty six fuel bundles were loaded in the three channels pointed out in Fig. 3.

At the end of March 1985, the defected fuel location system showed levels that forced to perform reshuffling operations in the three channels.

The burn-up of the extracted fuel bundles was in the range of 7600 and 1500 MWd/tU.

Four fuel bundles were found defected through post-irradiation visual examination.

It was not possible to establish the causes of defects in three fuel bundles.

The defect in the fourth one was due to the fact that a fuel rod was loaded with one missing pellet.

Only four fuel rods were affected out of 24 fuel bundles. The rest of the rods and of the fuel bundles did not present any peculiarity.

The irradiation program went on with the beginning of the second phase. Among other things, this phase foresaw the behaviour evaluation of those fuel bundles manufactured with an end caps automatic welding machine.

The resulst obtained from the irradiation up to that moment caused that some modifications in the set criteria were performed. So, the quantity of fuel bundles previously fixed for being loaded was increased, but instead of introducing them in the central channels, they were mainly loaded in the outer ones (Fig. 4).

During this second phase, 442 fuel bundles were loaded between March and May 1985.

In August, the defected fuel location system identified six suspicious channels.

The situation in the reactor and the already mentioned performance of the end caps welding machine, forced us to interrupt the reactor loading with domestic fuel.

The reduced number of defects that could be observed, and its characteristics, prevented us from concluding which was the source of the defects.

In case activity did not surpass acceptable limits, it was considered convenient to delay the unloading of suspicious channels as much as possible in order to gather more information that helped to evaluate the alternative problem sources.

As time passed, the number of suspicious channels and the activity levels increased. Because of that, it was necessary to begin unloading the most endangered channels. This process was precipitated in December 1985.

The preliminary analysis of the information available from the reactor, in-pool observation and production marked the end caps welding process, as possible responsible for the situation.

Failures did not seem to be due to any pattern referred to either the dwell time or the power.

The observation of defects led us to conclude that they were of secondary type. It was not possible to find evidence of primary defects, even in the end caps welding zone.

A work strategy was faced to confirm these assumptions.

In the production area, a manufacturing trace-back was performed with the help of documentation. After this, corrective actions were applied to the end cap welding operation.

At the same time, a post-irradiation program was implemented.

Based on the manufacturing and irradiation histories, and on the characteristics of defects obtained during in-pool observation, four fuel bundles were selected.

Each of these fuel bundles presented a visible piercing defect, of the kind of that presented in Fig. 5.

The fuel rods were removed from the assemblies and chopped in both end to extract the end caps with a piece of some milimeters of material from the cladding tube.

These operations were done at the Power Station pool, by means of devices specially designed and manufactured.

Through the macroscopical observation of the ends internal weldings, localized irregularities were detected and determined the places to perform the cuttings for metallographical tests.

These tests, performed in dry boxes, confirmed the existence of cracks in the welding zones as that presented in Fig. 6.

In the welding zone, a lack of continuity of the material can be seen. This has a maximum average width of 5 µm and extends circumpherencially in no more than 1 mm.

The defects morphology was similar to that detected in the quality controls of rejected manufacturing batches.

The epidemic-type of failures was related to the particular geometry of resistance welding clap electrode.

The manufacturing controls performed were based on statistical samplings that reduced the probability of detecting these kinds of defects.

The helium leak test was also inefficient for detection, because cracks developed and punctured the cladding during service.

Finally, the production consisting on welding batches of 72 fuel rods of the same version used for assembling different fuel bundles, would explain the high number of involved fuel bundles.

After corrective actions, the irradiation program was re-started last February, when 32 fuel bundles were loaded in the channels pointed out in Fig. 7.

At present, in the four channels there are fuel bundles that had reached extraction burn-up and the corresponding reshuffling operations have been faced. Their behaviour has been satisfactory, taking into account that in the final period thay were subjected to significant power cycling.

The previously loaded channels which probably contained defected fuel bundles, were progressively unloaded.

Here and now, 148 fuel bundles loaded during the second phase continue under irradiation without any signs of failure.

A balance performed after 701 full power days, (August 15, 1986) on domestic fuel bundles, supplied the following results:

. Unloaded up to the present with extraction burn-up		156
. Suspicious non-inspected	116	
. Suspicious inspected	72	
. Total of suspicious fuel bundles		188
. Total of confirmed defected fuel bundles		17
. Under irradiation		180
. Total of loaded fuel bundles		524

Taking into account that as an average, about two defective fuel bundles have been found in each reshuffling of 8 fuel bundles corresponding to the second phase loadings, it can be expected that this proportion be maintained in the 116 fuel bundles classified as suspicious non-inspected. This would imply a global rate of about 13% over the total of unloaded fuel bundles.

The maximum quantity of domestic fuel bundles simultaneously operating in the reactor was of 468. Fig. 8 shows the evolution of all the fuel bundles loades since the beginnings of the program.

There are no evidences of other peculiarities or deficiencies in the behaviour that could be attributed to other causes than the already mentioned ones.

We are confident on the effectiveness of the faced actions but it will be proved by the evolution of the presently used irradiation program.

6. CONCLUSIONS

The development of Candu fuel technology in Argentina has been completed from basic research until production scale including production equipment development.

This task extended itself during eight years including in-power reactor experience.

We have faced not only normal problems but in-reactor defects early reported by traditional Canadian Candu fuel manufacturers.

We have selected as welding processes the most advanced one from the point of view of metallographical processes but severe dimensional control are necessary for the welding electrode.

At present, we have re-started the mass production and loading in the power reactor.

ACKNOWLEDGEMENT

We must acknowledge the encouraging support received from the Power Station staff, which allowed us to investigate and solve the problems in a very short time.

In addition, the excellent work done for the post-irradiation examination and in glove box metallographic studies by Messrs. G. Ruggirello and J. Valesi, allowed us to reach a happy end in this work.

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(7) R.O. Cirimello, E.E. Pérez, O. Saracco, S. Harriague, "Recent Developments in Power Reactor Fuel in Argentina", International Symposium on Improvements in Water Reactor Fuel Technology and Utilization", Stockholm-Sweden, 1986.

TABLE 1: Comparison of BACO Code predictions vs. experimental results taken from M.J.F. Notley AECL 6585 (1980).

ELEMENT	VOLUME OF FISSION GAS RELEASED (cm^3 at spt)		EXTENSION OF COLUMNAR GRAIN GROWTH (fraction pellet radius)	
	Measured	BACO Prediction	Measured	BACO Prediction
HZB	10.6	10.0	.71	.62
HZC	11.5	10.0	.65	.62
HCD	9.8	9.9	.69	.62
HZH	0.1	0.0	0	0
HZE	12.3	11.4	.70	.62
HZF	17.4	13.0	.72	.62
MYZ	13.7	13.0	.72	.62
MY5	2.1	1.2	.43	.47

TABLE 2: Fundamental Studies and Main Goals

STUDY	MAIN GOAL
BACO Code simulation of power cycling operation (2)	Material properties and differential behaviour to steady state operation.
Stress relieved effects on SCC failure probability of Zry-4 tubes (3)	Study of stress relaxation in stress relieved Zry tubes submitted to brazing processes.
Effects of Heating Cycle length on cladding ductility and strength (4)	Quantitative loss of ductility by single and double Heating Cycle.
Effects of brazing on corrosion properties (5)	Differential corrosion rate and oxide morphology in this zone.
SCC susceptibility of HAZ near bearing pad brazing (6)	Differential SCC failure rate of tube in this zone.
Metallographical studies on resistance welding zone.	Welding parameters correlation with joint quality.

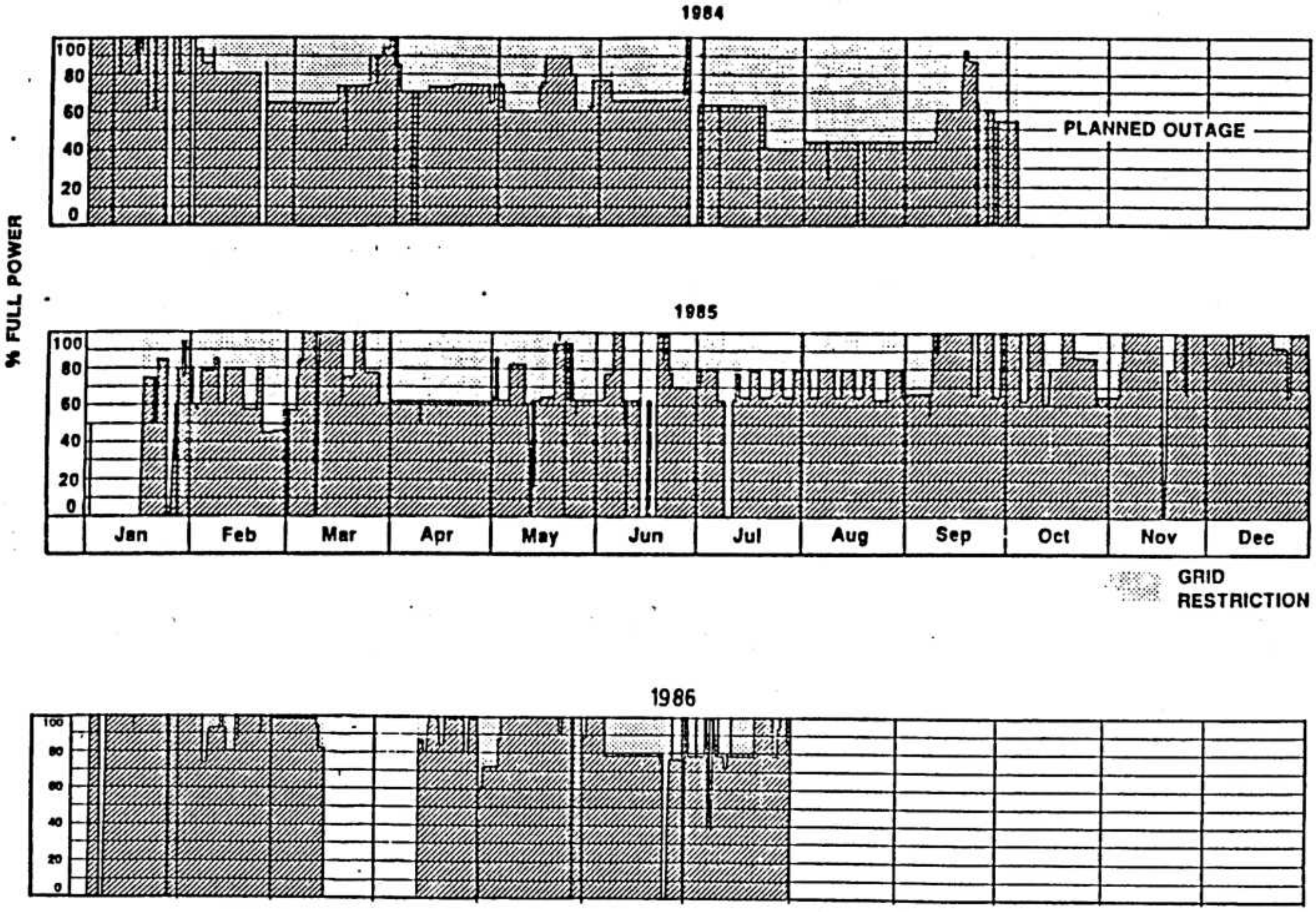
1984
100
80
60
40
20
0
PLANNED OUTAGE
% FULL POWER
1985
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
GRID RESTRICTION
1986
100
80
60
40
20
0

FIGURE 1

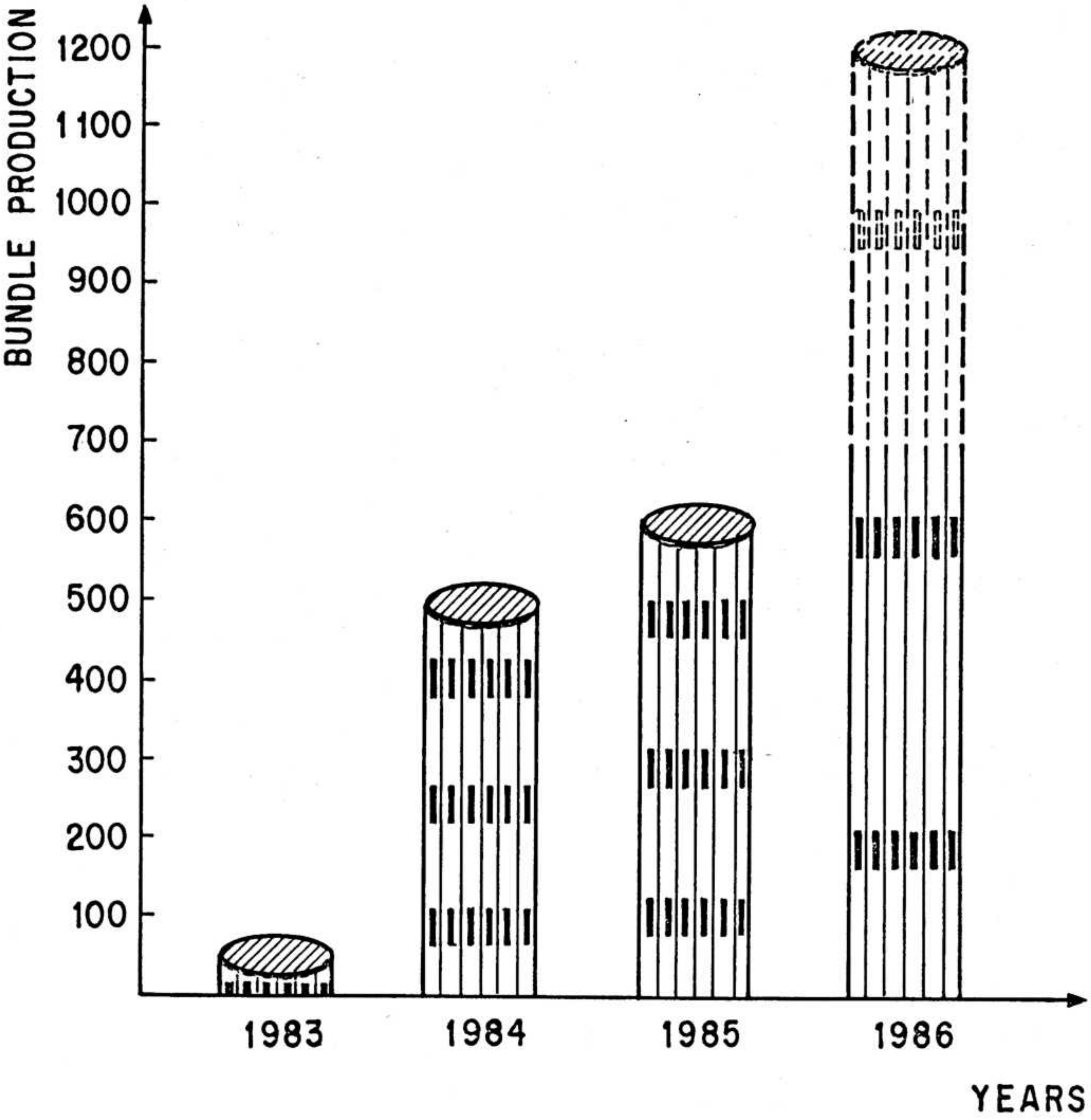
BUNDLE PRODUCTION
1200
1100
1000
900
800
700
600
500
400
300
200
100
1983
1984
1985
1986
YEARS

FIGURE 2

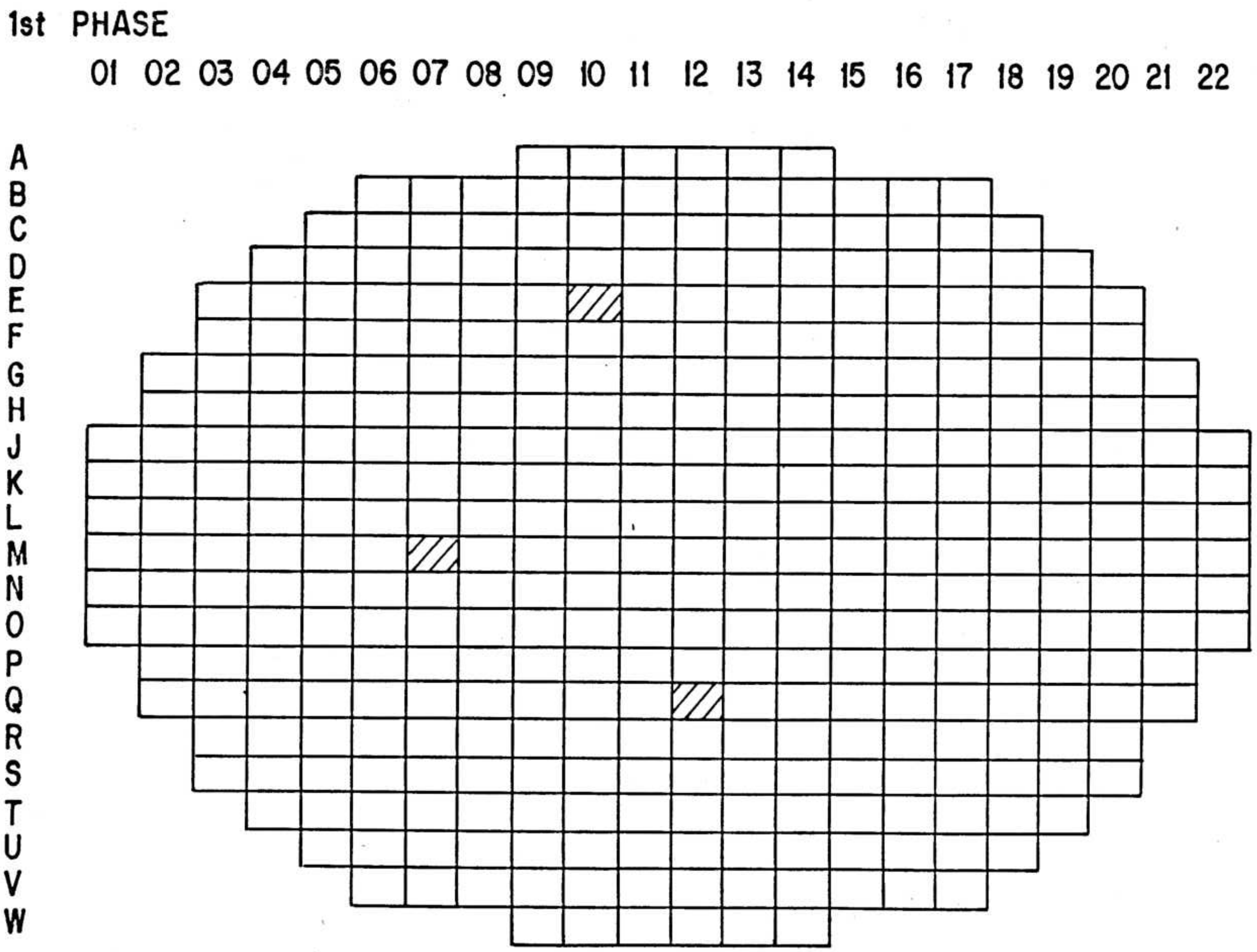
1st PHASE
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
A
B
C
D
E
F
G
H
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

FIGURE 3

2nd PHASE

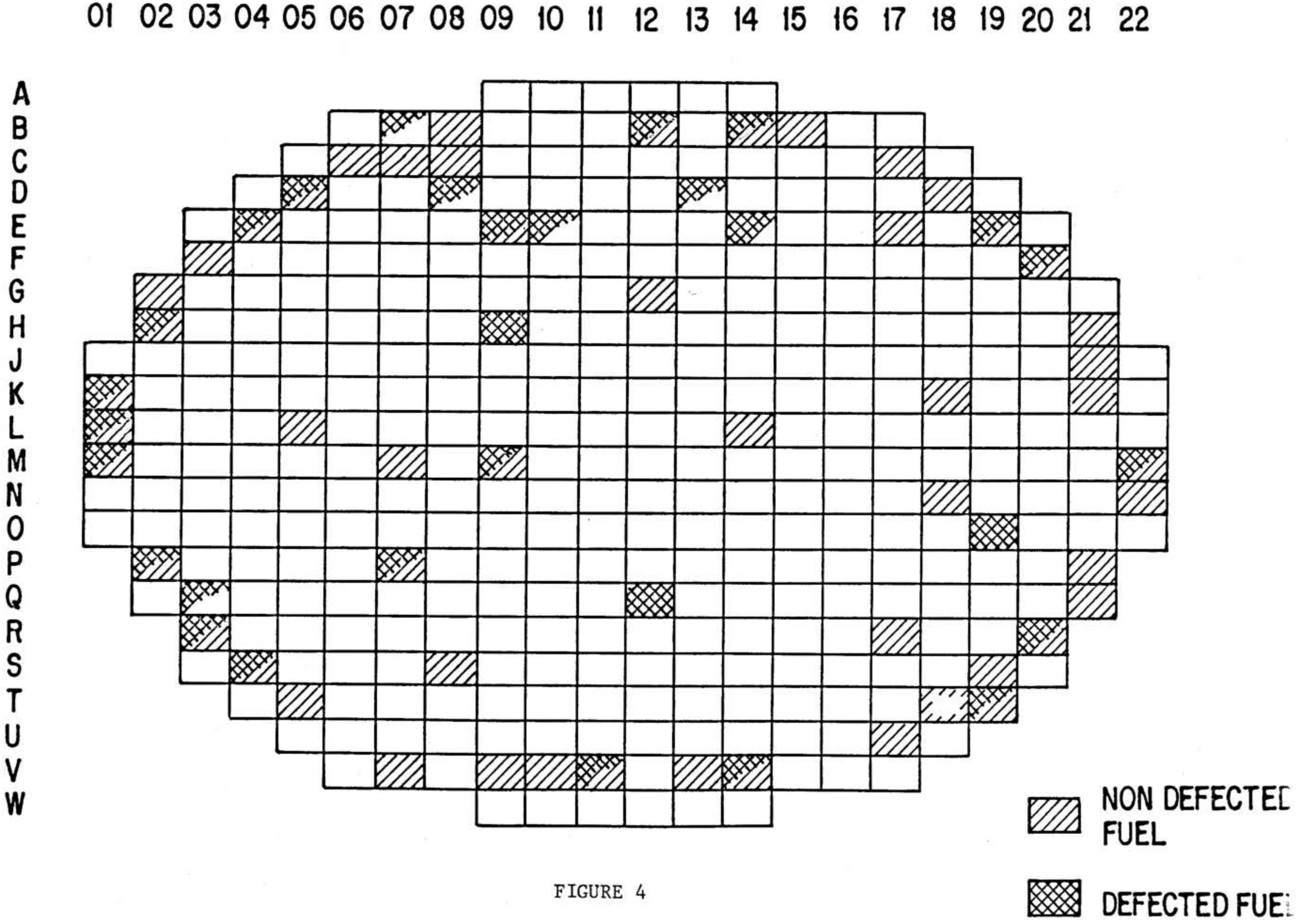

FIGURE 4

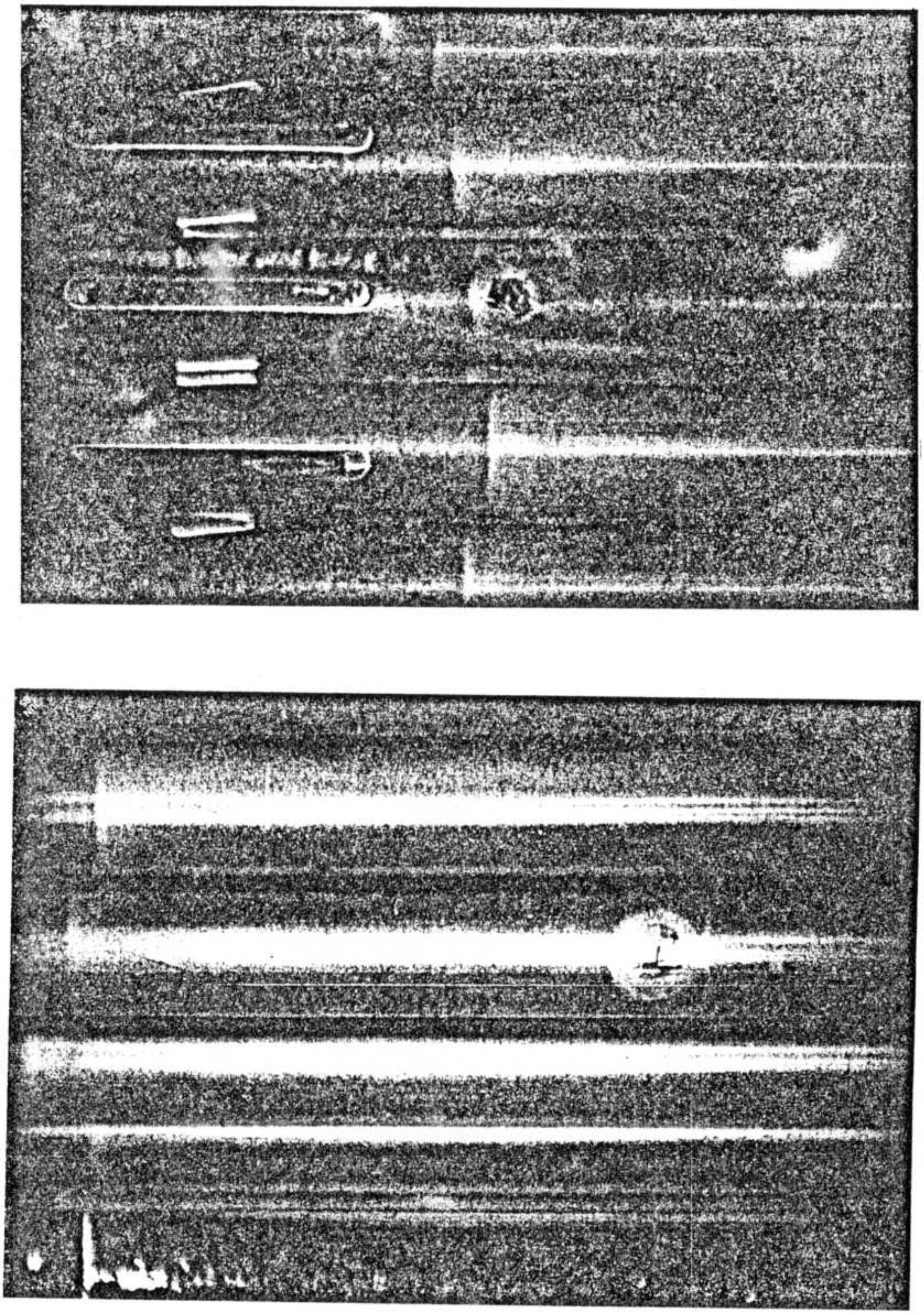

FIGURE 5

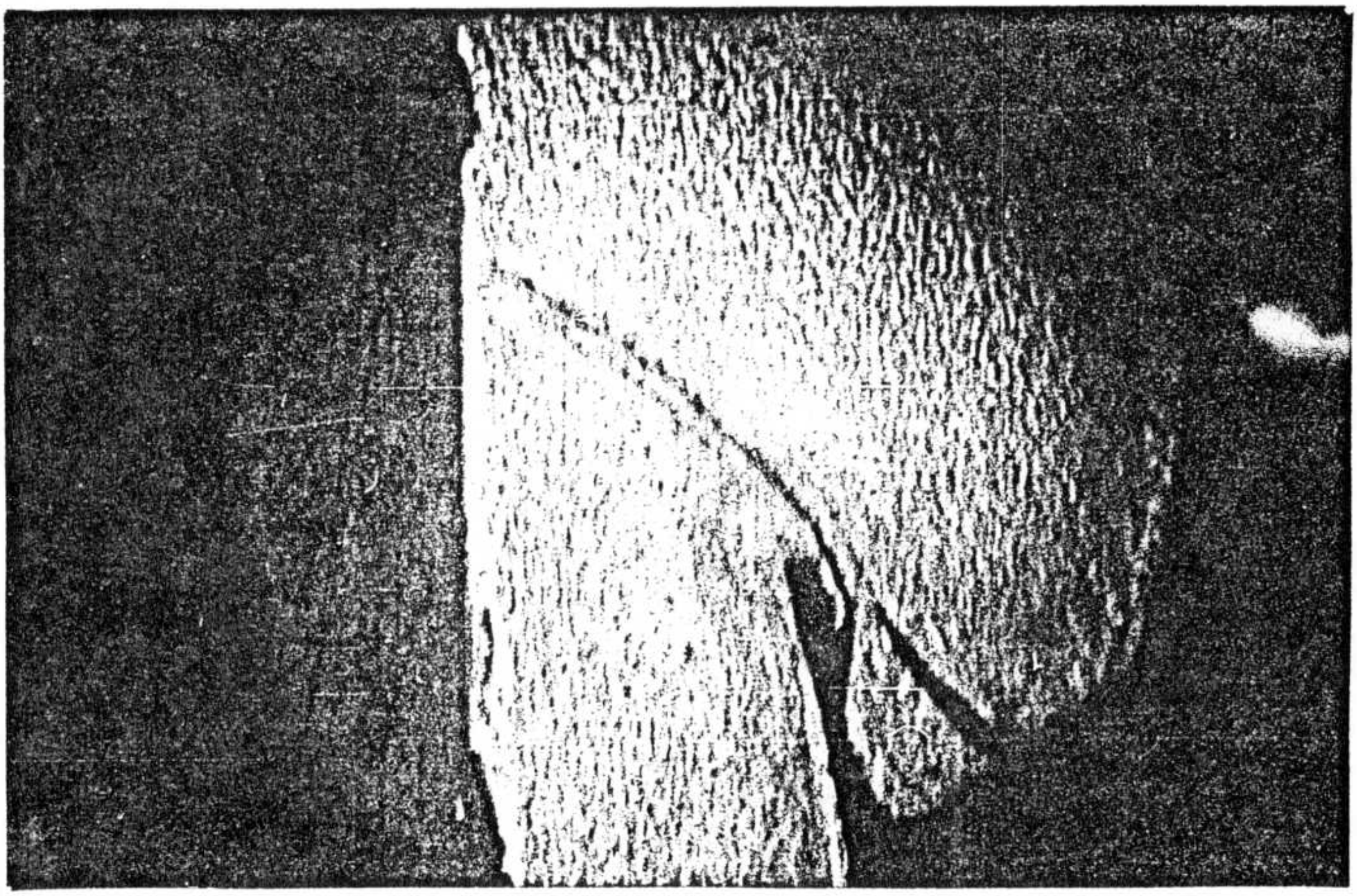

FIGURE 6

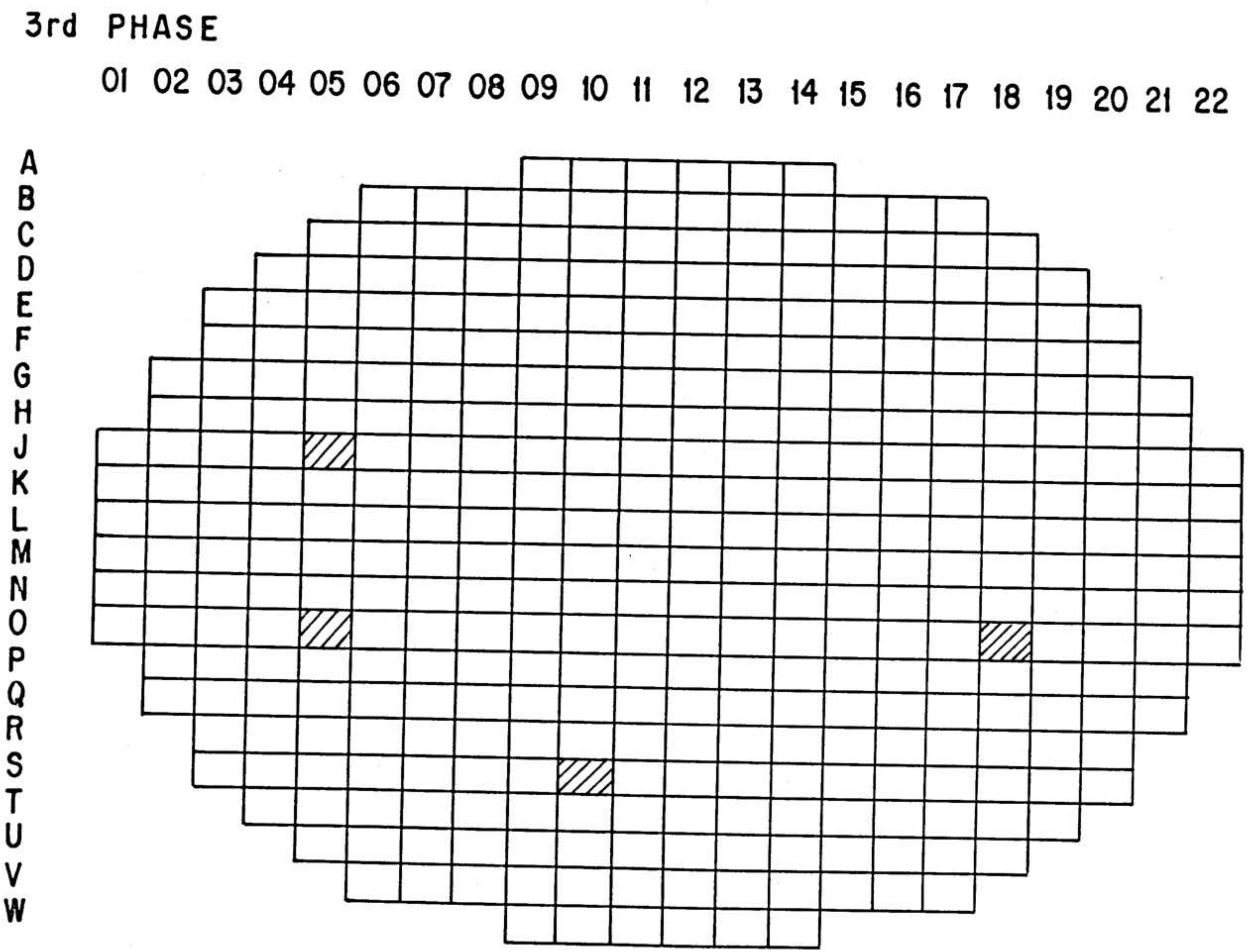
3rd PHASE
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
A
B
C
D
E
F
G
H
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

FIGURE 7

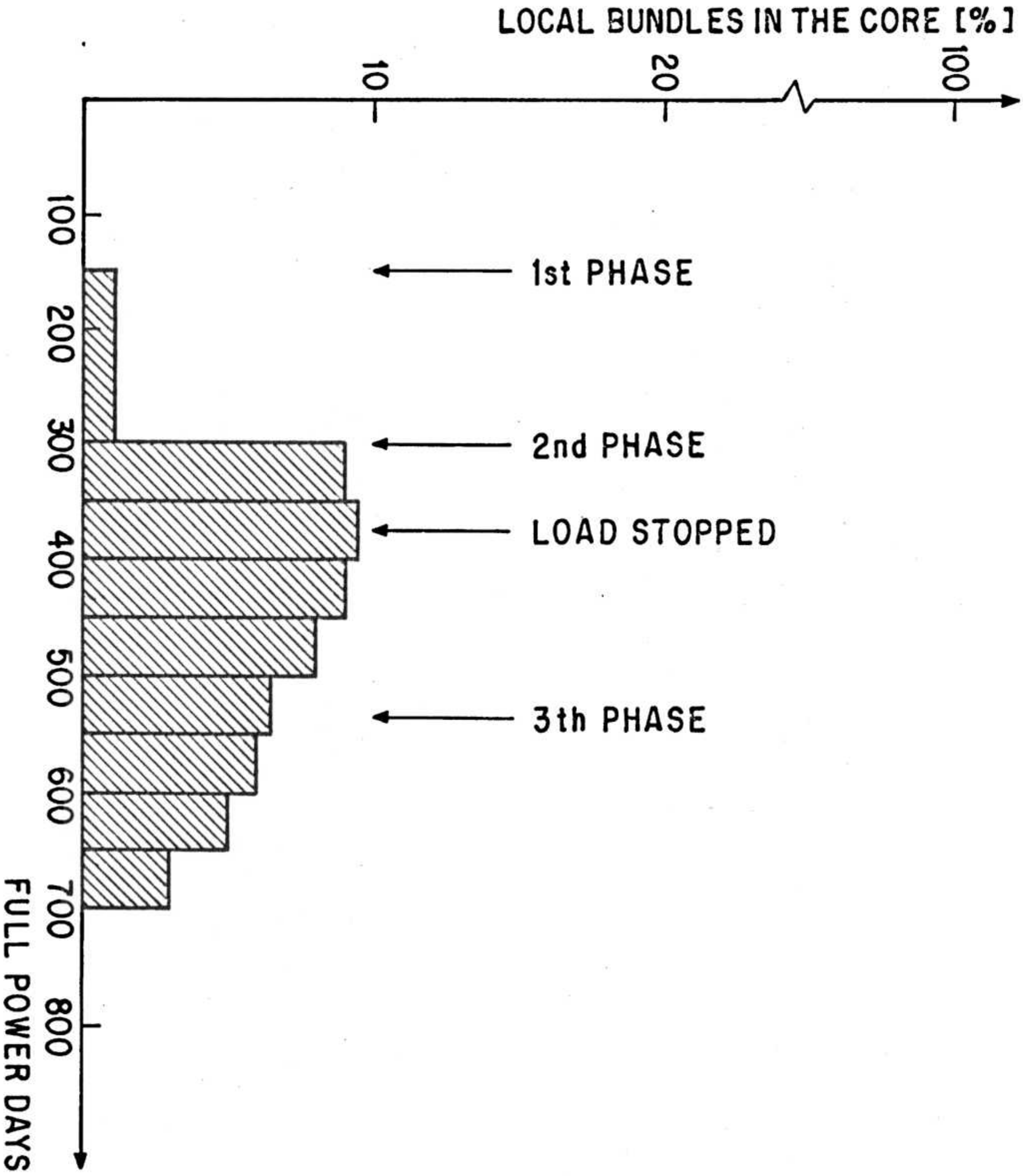
LOCAL BUNDLES IN THE CORE [%]
10
20
100
100
200
300
400
500
600
700
800
FULL POWER DAYS
1st PHASE
2nd PHASE
LOAD STOPPED
3th PHASE

FIGURE 8