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POWER UP OF FUGEN REACTOR
AND
DEVELOPMENT OF DEMONSTRATION PLANT

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Power up of FUGEN Reactor and[1],[2] Development of Demonstration Plant[3]

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1. The FUGEN Nuclear Power Station (Fig. 1) is a 165 MWe prototype plant featuring a heavy water-moderated boiling light water-cooled pressure tube type, and developed by the Power Reactor and Nuclear Fuel Development Corporation, Japan. Its construction began at Tsuruga, Fukui-prefecture, on December 1, 1970, and the plant went into commercial operation on March 20, 1979. Some major delays occurred in the overall program due to shortage of cement caused by the oil crisis, more stringent regulations as the result of stress corrosion cracking experienced in BWR and the need for design modifications. Over the last two years, however, plans have proceeded on schedule.

2. The core configuration of FUGEN is shown in Fig. 2. 96 mixed oxide fuel assemblies (0.66 % of Pu fissile + natural U) are loaded in the center region of the core and 124 slightly enriched uranium oxide fuel assemblies (1.5 % ^{235}U) surround them; thereby expecting that the reactor characteristics, especially the coolant void reactivity, would be changed a little throughout the reactor life. 4 special fuel assemblies, which contain test specimens of the pressure tubes in their center, are set at the position of 3-3, as shown in Fig. 2. The special fuel assemblies are so designed that nvt of the specimens exposed may be expected to be 10 to 20 % higher than that of the pressure tubes. The specimens will be tested at intervals of 2 to 5 years, especially to check their ductility.

3. All functional tests, the final check of the whole plant and some remaining modification works had been completed by March 10, 1978. In-site-stress-relieving of the pressure tube rolled joints was carried out from January to February 1978. During the period of March 1978 to March 1979, tests were carried out comprised the following:

(1) reactor physics,
(2) plant dynamics,
(3) performance of major components and systems,
(4) radiation and water chemistry.

These were performed at cold zero energy, nuclear heating and power raising stages of the plant (Fig. 3).

4. Minimum criticality was achieved with 22 mixed oxide fuel assemblies on March 20, 1978 with the central control rod partially inserted into the core, which shows good agreement with the calculated quantity of 20 fuel assemblies.

Fuel loading was done using the computer controlled refueling machine at a speed of 6 to 9 fuel assemblies in a day. After the formation of a partial core of 96 mixed oxide fuel assemblies with 4 special fuel assemblies, as well as on the completion of full core, a series of cold zero energy physics measurements, such as control rod worth, liquid poison worth, etc., was performed. Reactor physics data at criticality are shown in Table 2.

5. On June 13, 1978, tests on the reactor nuclear heating were started. Generated steam was dumped to the turbine condenser through the bypass line. The object of the nuclear heating tests was to prove the capability of the plant before raising power. During this plant operation, measurements were made to check the performance of plant systems, system components and thermal expansion movements of pipework. In addition to the above mentioned

measurements, the coolant temperature coefficient of reactivity was measured (Table 3).

In this period, we encountered some difficulty in controlling the water level of steam drums, when we tried to keep the temperature of coolant at about 100°C in order to measure the thermal expansion movements of pipeworks, etc. Between two primary loops, some difference was found in the coolant flow to the purification system which is common for each loop; which gave us above difficulty. It was soon found that this phenomenon was caused by the pressure drop difference between two piping systems connected to the purification system. The problem was solved by controlling the coolant flow to the purification system: and, we have no problem in the reactor operation at present.

6. On July 29, 1978, the turbine generator was synchronized, sending 5 MWe to the grid system. At each stage of power levels, i.e. 25, 50, 75 and 100 %, measurements on core performance, survey of radiation levels, measurements on water chemistry, tests on the major control systems were carried out. Plant shutdown tests, such as load rejection, turbine trip, recirculation pump trip, main steam isolation valve closure and power black-out, were also done; and no unscheduled trip had been encountered during the power raising period.

Reactivity coefficients measured are shown in Table 3, comparing with calculated values.

The test result of plant dynamic characteristics at load rejection (100 % power level) are shown in Fig. 4. As the turbine regulating valve was shut off immediately, the pressure of the steam drum was increased as high as about 72 kg/cm^2 g, and then went down with leading steam to the condenser through turbine bypass valves. The turbine speed was increased by about 5 % and was soon settled down to the defined value, and the turbine was tripped 30 sec after the load rejection.

7. Evaluation of core performance shows that the maximum liner heat rate of fuel rod would be about 13 kw/ft which is lower than designed. In order to achieve the pre-conditioning of fuels when the reactor was started up after a fairy long shutdown period, say 3 weeks or more, we have restricted the power raising rate to 0.4 %/hr above 8 kw/ft (about 50 % of full power).

Plant dynamic characteristics have been very stable against disturbances of the reactor pressure and the feed water flow. This will result from the zero coolant void reactivity coefficient in FUGEN.

Fig. 5 shows the plant dynamic characteristics when the power level be decreased by 10 %.

The result of the feed water pump trip test is shown in Fig. 6. The feed water flow was decreased at first, however it was recovered in 10 sec, as a spare feed water pump was soon started.

8. To date, the concentration of Iodine-131 in the reactor coolant is a order of 10^{-6} μCi/cc. This proves that there may be no defect in fuels. By use of injection of oxygen into the reactor feed water, the concentration of iron has been successfully reduced in the coolant.

Commercial operation of the plant was licensed by the Government, on March 30, 1979 --- on the completion of continuous 100 hours full load operation.

9. The role of FUGEN type reactors in Japan is now understood to utilize fuels effectively, Pu and depleted U derived from the operation of Light Water Reactors.

A conceptual design of the 600 MWe demonstration plant was finished in early 1979 and its detailed design is to be carried out in the fiscal year of 1979 and 1980.

Main design principle of FUGEN was incorporated in the above conceptual design, as seen in Table-1.

Some modifications, however, are to be made to reduce power cost and to facilitate easier maintenance.

(1) Pu content of mixed oxide fuels will be taken so as to give almost the same fuel burn-up of Light Water Reactors,

(2) 36 rod-cluster fuel assembly is used instead of 28 to reduce the size of core,

(3) Heavy water damp space in the calandria is eliminated,

(4) Components used in normal reactor operation, such as the feed water pump, etc., are designed to be used in loss of coolant accident: thereby giving higher reliability in the ECCS and so on.

In parallel with the design work, experiments on core heat removal and nuclear characteristics have been started, using 14 MW heat transfer loop and critical assembly.

A concenptual design of a mixed oxide fuel fabrication plant is also being done.

References

(1) Y. MIYAWAKI: "Zero Power Startup Tests of FUGEN" J. of Atomic Energy Society of Japan, Vol. 20, No.7, July, 1978

(2) S. SHIMA and M. AKEBI: "The FUGEN Project - Construction and Startup" Transactions of the Second Pacific Basin Conf., ANS, Sept., 1978

(3) S. SAWAI, et al: "Advanced Reactor Development in Japan" Transactions of the Second Pacific Basin Conf., ANS, Sept., 1978

Table 1

Design Data of FUGEN and Demonstration Plant

	FUGEN	Demo. Plant
Electric power (MW)	165	600
Thermal power (MW)	557	2000
No. of channels	224	648
Core height (mm)	3700	3700
Pressure tube		
Material	Zr-Nb	Zr-Nb
i.d. (mm)	118	118
Thickness (mm)	4.3	4.3
Fuel		
No. of rods	28	36
Pellet diam (mm)	14.4	12.3
Pu enrichment (%)	0.66	1.44
Refueling	To demonstrate on-power	Off-power

Table 2

Reactor Physics Data on Criticality of FUGEN

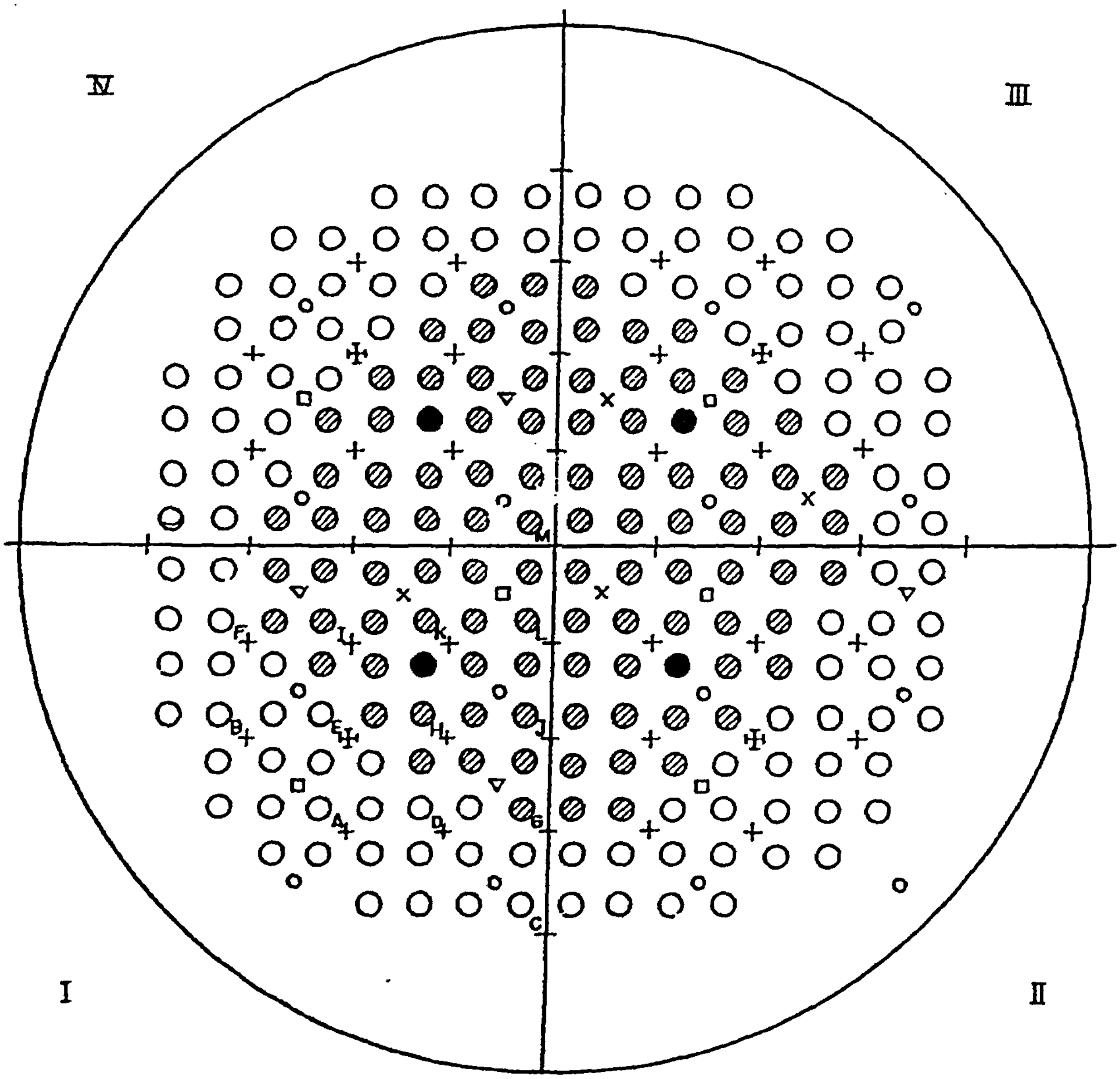
	Min. Criticality Core	100 Fuels Core	Full Core
Fuel			
Mixed Oxide Fuels	22	96	96
Special Fuels	0	4	4
U Oxide Fuels	0	0	124
Content of ^{10}B (ppm)	less than 0.005	10.3	12.9
Temp. of D_2O (°C)	11.9	14.2	16.0
Temp. of H_2O (°C)	16.0	16.0	24.0
Position of Central Control Rod (%)	56.3	67.0	67.5

Table 3

Reactivity Coefficients
(Measured and Predicted)

	Measured	Predicted
Power Coeff. ($\Delta k/k/\Delta P/P$)	$(-8 \pm 2) \times 10^{-3}$	$(-7.5 \pm 2.4) \times 10^{-3}$
Coolant Void Coeff. ($\Delta k/k/\%$ Void)	$(0 \pm 0.2) \times 10^{-4}$	$(0 \pm 0.5) \times 10^{-4}$
Coolant Temp. Coeff. ($\Delta k/k/°C$)	$(-6 \pm 2) \times 10^{-5}$	$(-6 \pm 3) \times 10^{-5}$
Moderator Temp. Coeff. ($\Delta k/k/°C$)	$(2 \pm 1) \times 10^{-4}$	$(2.3 \pm 1.2) \times 10^{-4}$

Fig. 1 GENERAL VIEW OF FUGEN PLANT



		No.			
○	Oxidefuel (UO_2)	124	o	Local power monitor	16×4
⊘	Mixed oxide fuel (PuO_2+UO_2)	96	□	Power-up monitor	6
●	Special fuel	4	▽	Start-up monitor	4
+	Control rod	45	×	Fuel loading monitor	4
╪	Regulating rod	4			

Fig. 2 CORE CONFIGURATION OF "FUGEN"

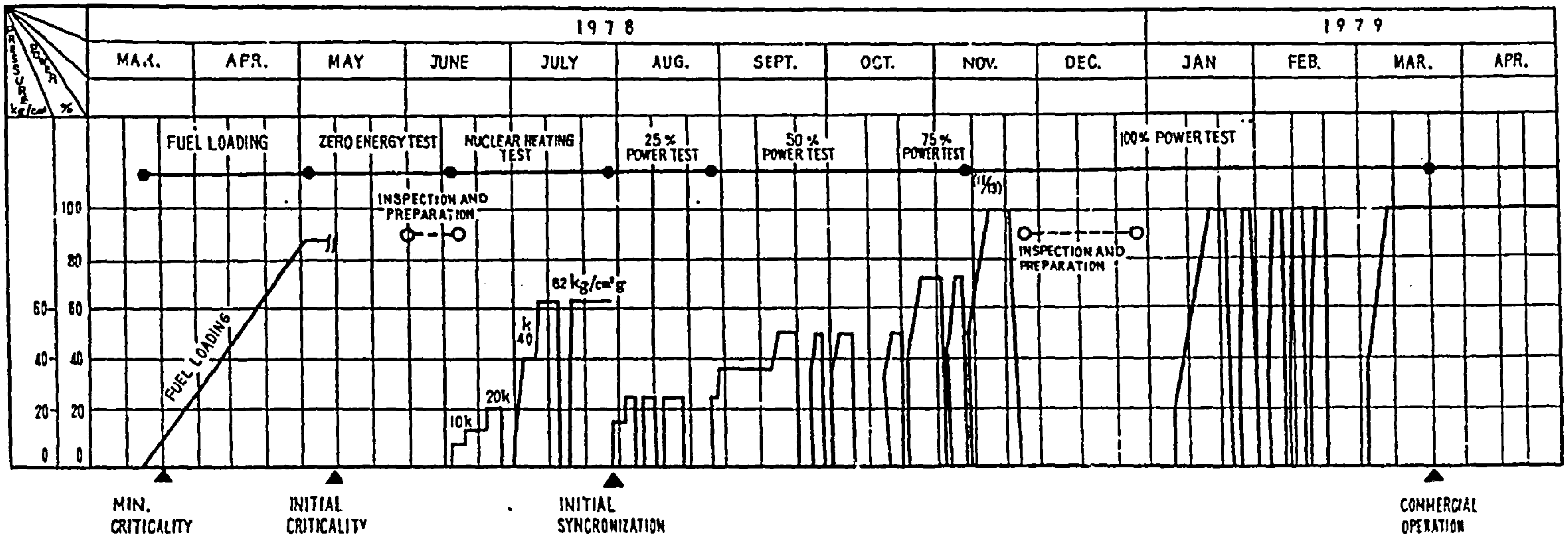


Fig. 3 SCHEDULE OF POWER-UP TEST

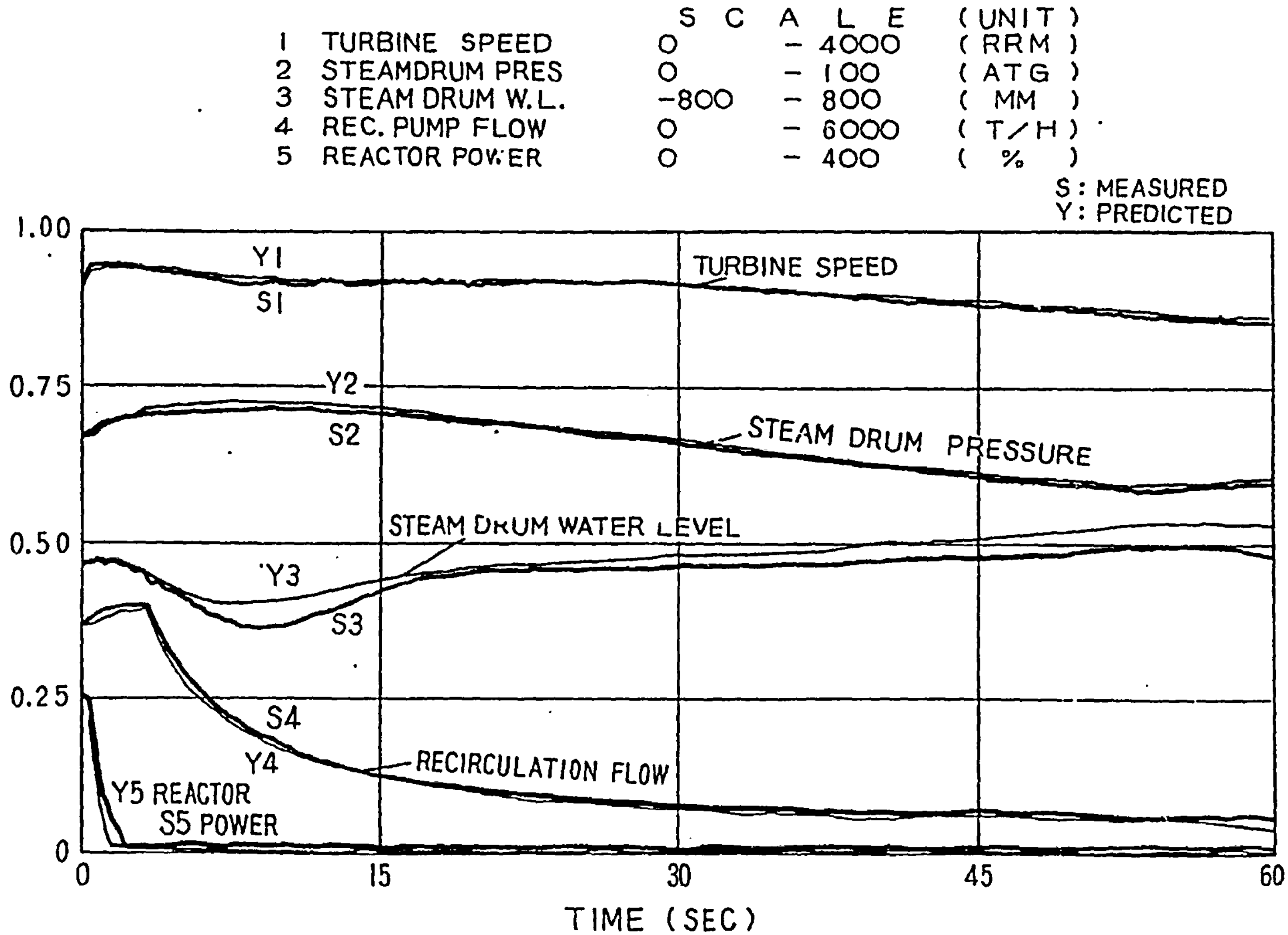


Fig. 4 PLANT DYNAMIC CHARACTERISTICS AT LOAD REJECTION (FULL POWER)

		SCALE		(UNIT)
1	GENERATOR POWER	0	- 140	(MW)
2	REACTOR ROWER	0	- 100	(%)
3	STEAM FLOW	0	- 700	(T/H)
4	STEAMDRUM PRES.	50	- 100	(ATG)
5	STEAM DRUM WL	-100	- 700	(MM)

S: MEASURED
Y: PREDICTED

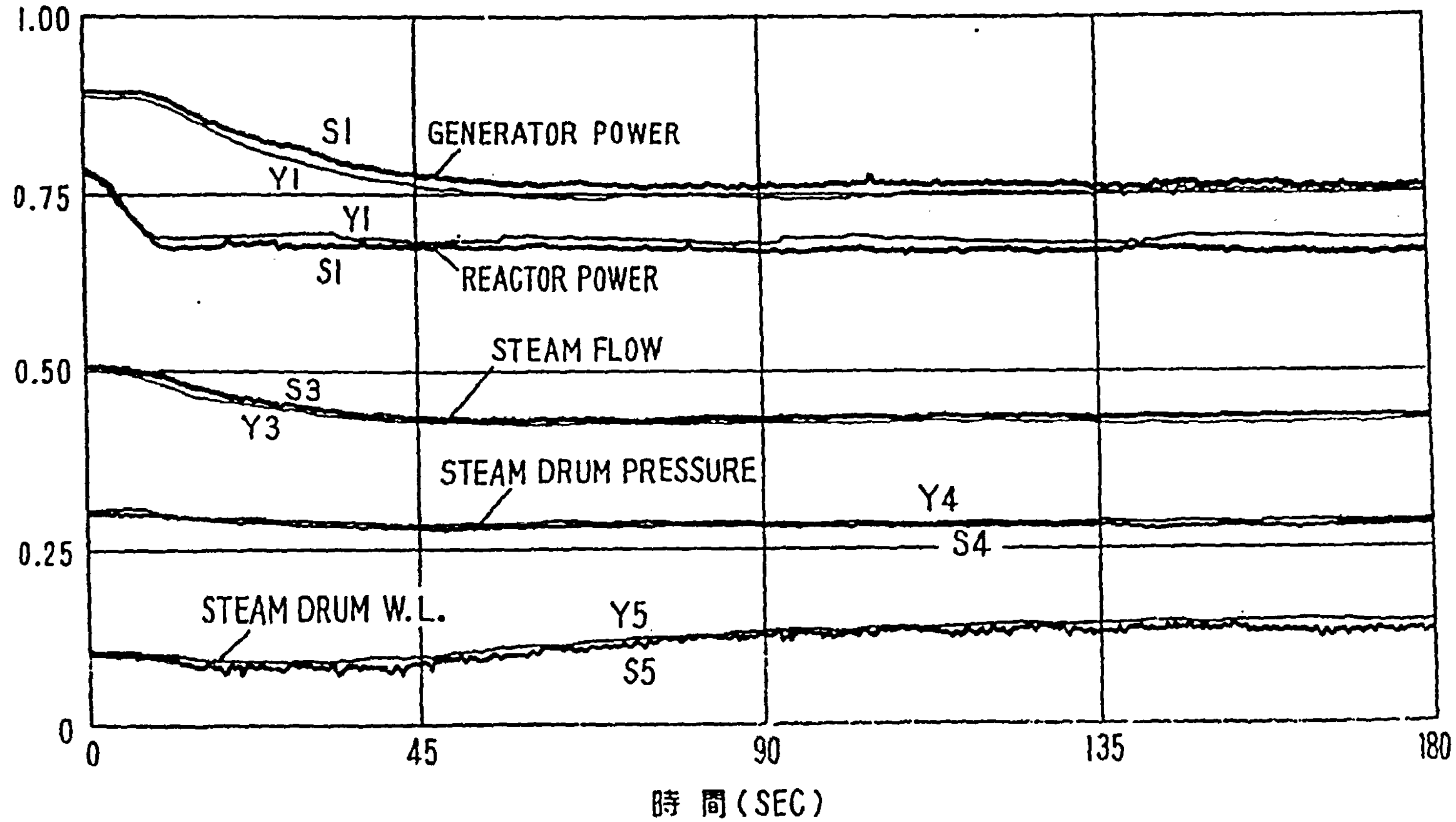


Fig. 5 PLANT DYNAMIC CHARACTERISTICS
AT POWER CHANGE (10% DOWN, 75% POWER)

		S C A L E		(UNIT)
1	GENERATOR POWER	0	- 200	(MW)
2	REACTOR POWER	0	- 130	(%)
3	STEAM FLOW	0	- 700	(T/H)
4	FEEDWATER FLOW	100	- 800	(T/H)
5	STEAM DRUM W.L.	-300	- 900	(MM)

S : MEASURED
Y : PREDICTED

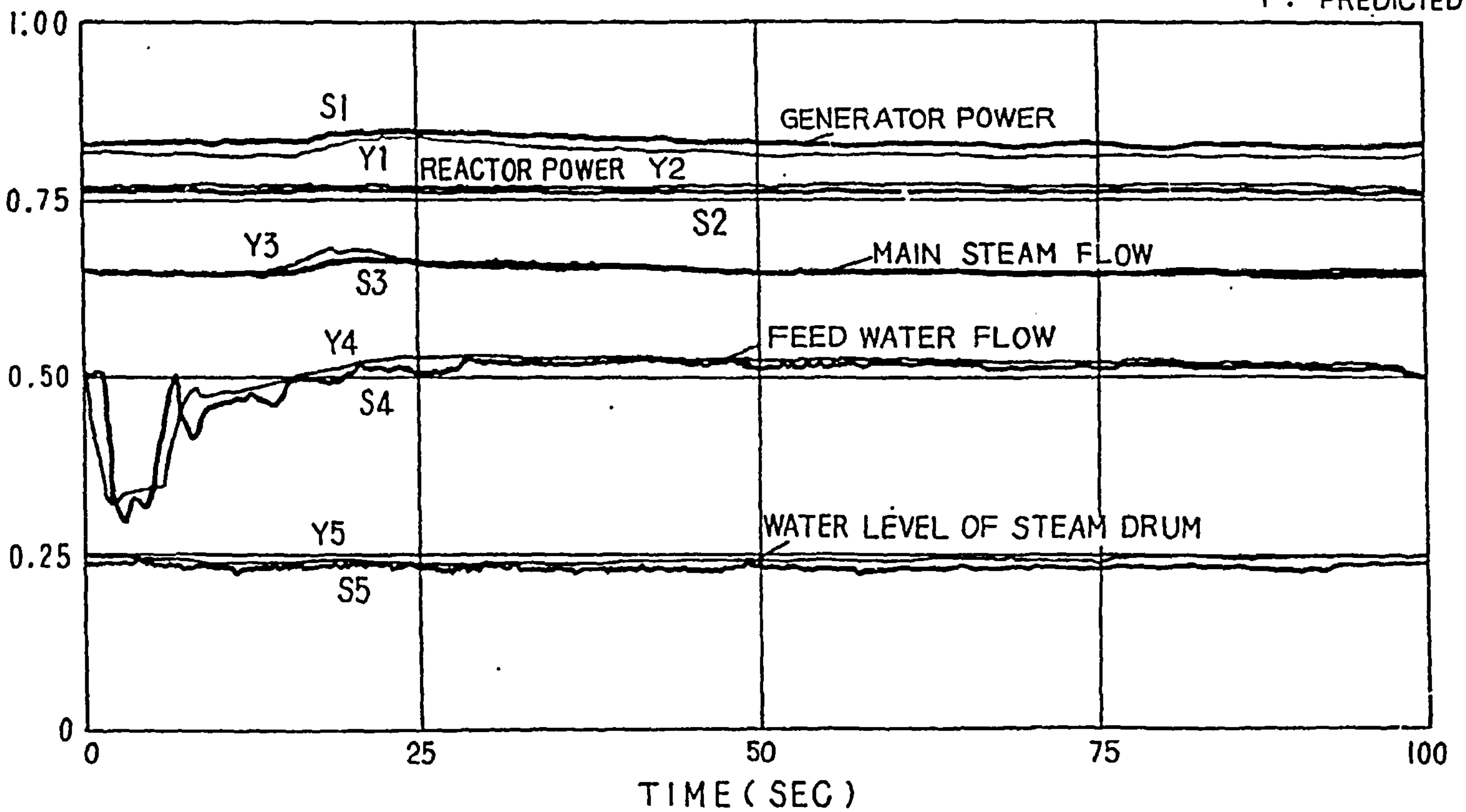


Fig. 6 PLANT DYNAMIC CHARACTERISTICS AT FEED WATER PUMP TRIP (FULL POWER)