An Analysis of 50% High Pressure Feedwater Bypass Operation With PEPSE®

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ABSTRACT

PEPSE has been applied to the power plant performance evaluation in KOREA since 1984. This paper introduces the analysis of High Pressure Feedwater Bypass Operation of Kori Nuclear Power Plant No.1. When one of the feedwater heaters is out of service for maintenance, load reduction is necessary in order to protect turbine. PEPSE is used to evaluate proper turbine load reduction of 50% high pressure feedwater bypass operation.

As a result of the analysis, the calculated power reduction has revealed much smaller than the vendor recommendations. If the plant safety is proved through in-field test, Kori NPP No.1 can be operated at a small load reduction with one train of high pressure feedwater heaters out of service.

1.0 INTRODUCTION

Kori Nuclear Power Plant No.1 is 595 MWe Westinghouse two loop PWR with GEC tandum compound double flow reheat turbines. In normal operation, the dual trains of high pressure feedwater heaters are all in service. However if there happens any trouble in one train, it is necessary to bypass feedwater flow around it for maintenance. In this case, load reduction is required for a turbine protection. Vendors generally recommend 25 to 30% load reduction for one train operation. These recommendations are considered so conservative that a proper turbine load reduction is evaluated with PEPSE.

This paper presents PEPSE modeling, analysis procedure, safety evaluation, and suggests a proper turbine load reduction. The analysis is performed in the steady state operation of Kori NPP No.1 with design heat balance data. This result can be used as a new operation guideline if the plant safety is proved through in-field test.

2. 0 ANALYSIS

2. 1 OVERALL PROCEDURE

Feedwater system operation of nuclear trubine cycle is closely related with nuclear safety. 50% of HP feedwater bypass induces enthalpy drop of the steam generator in-flow. In order to compensate this enthalpy drop, reactor thermal power and main steam flow need to be reduced. PEPSE is applied to estimate a proper turbine load reduction for feedwater bypass operation. The nuclear safey of load reduction operation is checked by comparing the decrement of reactor power with that of turbine load. The overall analysis procedure of this study is shown in Figure 1.

After normal operation modeling of turbine cycle, its design heat balance data at 595MWe is input to PEPSE which calculates the reference data of heat balance. The calculated reference data usually does not coincide with the design heat balance data, but input data needs to be reviewed carefully to make the discrepancy as little as possible. This reference heat balance data becomes a standard criteria which decides thermal overload and safety of equipments and streams during analysis. All the operating variables of the analysis should not exceed the reference data values.

After preparing the reference data, the geometrical modeling is modified to reflect bypass operation. The heat balance of the modified modeling is re-calculated with PEPSE. Equipments or streams which are thermally overloaded are checked by comparing the bypass operation values with the reference data. If no overloaded equipments or streams are found, next steps can be proceeded. However, the operation variables such as flow rate, pressure, temperature, and enthalpy are input with the reference data, there occurs a number of mass and energy unbalance. A lot of overload phenomena are found in this step. These are usually appeared at turbine stage group flow coefficient, effectiveness of LP and HP feedwater heaters, and extraction steam flow rate. The above overload phenomena can be eliminated through adjusting the turbine cycle heat balance by tuning the PEPSE input data.

After clearing thermal overload, operational safety is reviewed. The safety review items are 1) trend of reactor thermal power and turbine power reduction, 2) increased flow velocity effects in streams, 3) effectiveness of the feedwater heaters, and 4) turbine flow coefficient.

If no deficiencies are found in safety items, a proper turbine load reduction is evaluated by comparing the turbine cycle performance parameters of the bypass operation with that of the reference data.

2. 2 GEOMETRICAL MODELING

For the HP feedwater bypass operation, some of the flow paths are required to be modified as shown in Figure 2. Dotted lines indicate the flow paths which have flows in normal operation but no flows in bypass operation. When the "B" train of the HP heaters (No.5B and 6B) is out of service, half of the HP extraction steam flow and MSR condensed drain is not supplied to the shell side of No.5B and 6B heaters. This reduced extraction steam flow of HP turbine is reflected in the turbine extraction flow input data. And half of the MSR condensed drain is physically dumped to condensers by flow path change.

The dump valves to the condensers are opened automatically by condensed water level high signal caused by closing the drain valves. Such a valve line-up for the bypass operation is consistent with the logic of system operation.

2. 3 HEAT BALANCE ADJUSTMENT

The heat balance of the bypass operation is obtained by running PEPSE with the reference data input to the modified modeling. At the first run, some unreasonable aspects may be found such as the inlet steam flow of the LP turbine section increasing, the turbine power increasing, the effectiveness of the LP feedwater heaters beyond 1.0, the condensate water flow increasing, and the reactor thermal power increasing. These unreasonable phenomena are corrected by tuning the PEPSE input data.

Above all, main steam flow rate reduction is done as much as the excluded extraction steam flow of the HP turbine stage groups. This eliminates most of the unreasonable phenomena but the condensate flow and LP heater effectiveness is still higher than the reference data. Increased condensate flow is due to dumping the drain flow of MSR to the condenser. This subsequently increases the LP feedwater flow and feedwater heater effectiveness even though the shell enthalpy drop maintains constant.

Increasing the shell inlet flow of the heater No.3 above the reference data can reduce the effectiveness of the LP heaters. When increasing the shell inlet flow, mass and energy balance of LP heaters has to be considered. The increased velocity of the shell inlet should not be in chocked flow condition, and should be lower than the flow induced vibration criteria of heater tubes.

After the above heat balance adjustment of bypass operation, the proper turbine power has appeared as 580.3 MWe which is 2.3% smaller than full power.

2.4 THERMAL OVERLOAD AND SAFETY

The safety criteria of this analysis is basically the reference heat balance data. Although mass and energy balance is properly adjusted, some overloaded components are still appeared. This is because of the abnormal condition of bypass operation.

Major overloads are the heater No.3 shell inlet and LP heater tube inlet flow high. These increased flow rate raise the flow velocity and may cause damage by phenomena such as chocked flow, erosion, and flow induced vibration.

When the flow velocity in pipe is higher than acoustic velocity, a chocked flow phenomenon happens. The acoustic velocity which is the possible maximum velocity in the pipe is expressed as

$$C = \sqrt{Es/\rho} \quad \text{for a fluid}$$

$$C = \sqrt{kgRT} \quad \text{for an ideal gas}$$

where C = acoustic velocity, Es = isentropic bulk modulus of elasticity, ρ = density of a fluid, k = ratio of specific heats, g = gravitational acceleration, R = molecular weight, and T = absolute temperature.

The calculated flow velocities in the feedwater and extraction pipes, of which flow rates are above the reference data, is verified below the chocked flow condition.

Increased flow velocities may accelerate erosion of pipe line, but they have appeared below the Maximum Tube Velocity of Heat Exchange Institute, i.e. 10 ft/sec in this case. So it could be concluded that severe erosion damage may not be taken place.

Increased shell side flow may cause flow induced vibration to the tube bundle. Unfortunately PEPSE does not have the function to analyze this vibration so that flow induced vibration problem is not studied in this work. However this is the area to be improved further in PEPSE in order to analyze abnormal operating conditions, and needs further studies.

The other important safety parameters are reactor thermal power, turbine flow coefficient, and feedwater heater effectiveness. The calculated reactor thermal power is decreased 2.9% when the turbine load is decreased 2.3%. This small discrepancy between them is due to the steam generator lumped modeling. Considering the trend of their decrements and values, it is supposed that there will not be any safety problem in the nuclear steam supply system. For turbine flow coefficients, no overload was found because the steam flow rate of each turbine stage groups were input according to the reference data. The effectiveness of all the feedwater heaters was adjusted below 1.0 during the analysis in order to meet the overload limitation.

3. RESULTS AND DISCUSSION

The major performance parameters of this study are shown in Table 1. It is notable that the heat rate of bypass operation is decreased (increasing is normal) even though the main steam flow rate is reduced. This is because PEPSE has just lumped modeling function of steam generator instead of detail modeling. If detail modeling of steam generator is included in PEPSE, this problem is expected to be solved.

Effectiveness of the feedwater heaters is shown in Table 2, and flow deviation in feedwater side is shown in Figure 3. The turbine cycle regeneration effect of bypass operation is reduced as much as the enthalpy drop of the terminal feedwater entering the steam generator.

PEPSE calculated the proper turbine power of 50% HP feedwater bypass operation as 580.3 MWe which is 2.3% smaller than full power. This power reduction is much smaller than general vendor recommendation of 25 to 30%. It is found from this study that PEPSE is very useful tool to re-assess such a conservative vendor operating recommendation.

4. SUMMARY

This study evaluated a proper turbine load reduction of 50% high pressure feedwater bypass operation in Kori NPP No.1. Analysis procedure has been introduced in the geometrical modeling, heat balance adjustment, and thermal overload and safety check.

It turns out from this study that Kori NPP No.1 can be operated with 3% load reduction when one train of the HP feedwater heaters is out of service.

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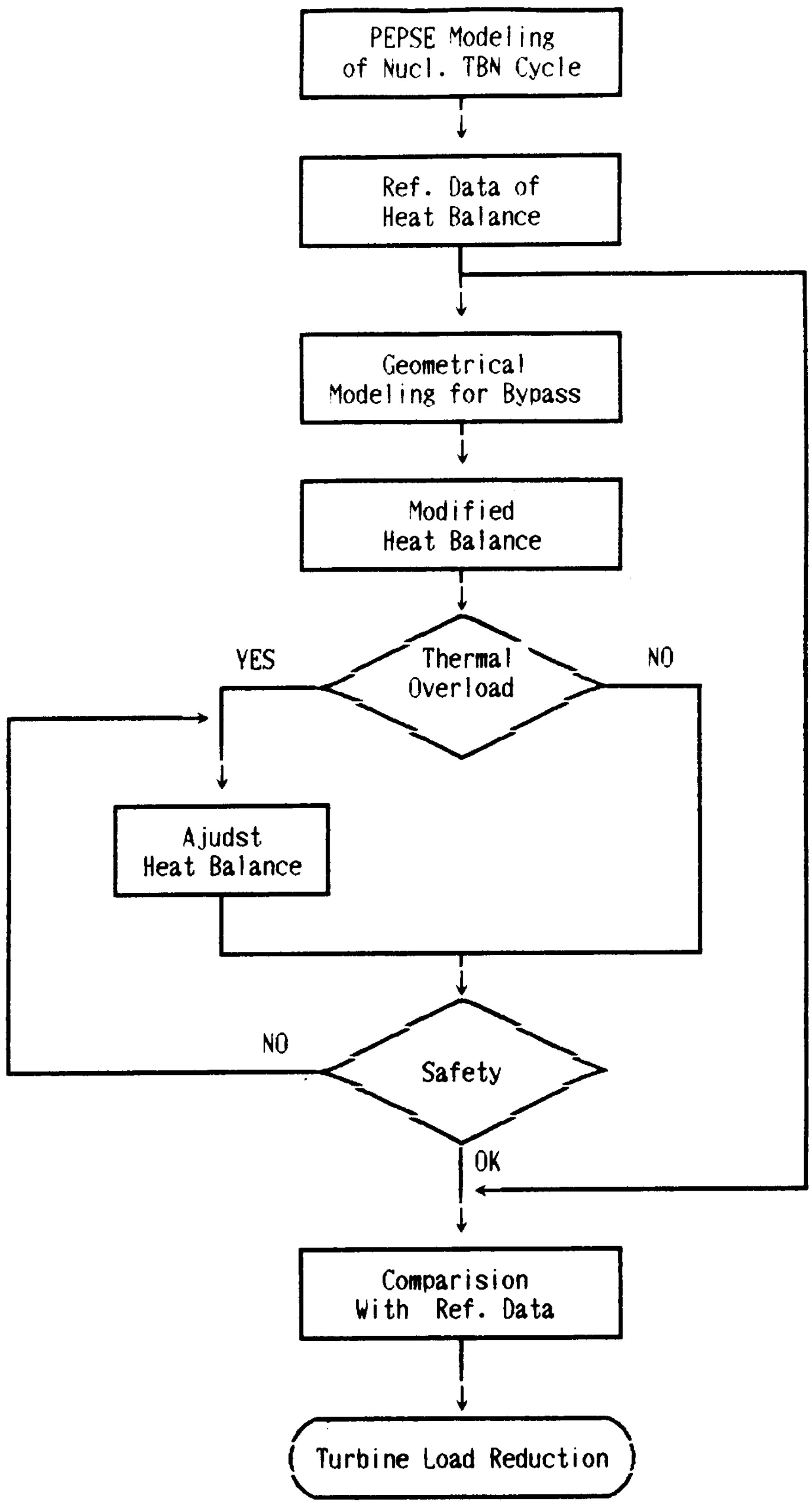

Fig.1 Analysis Procedure for Feedwater Bypass Operation

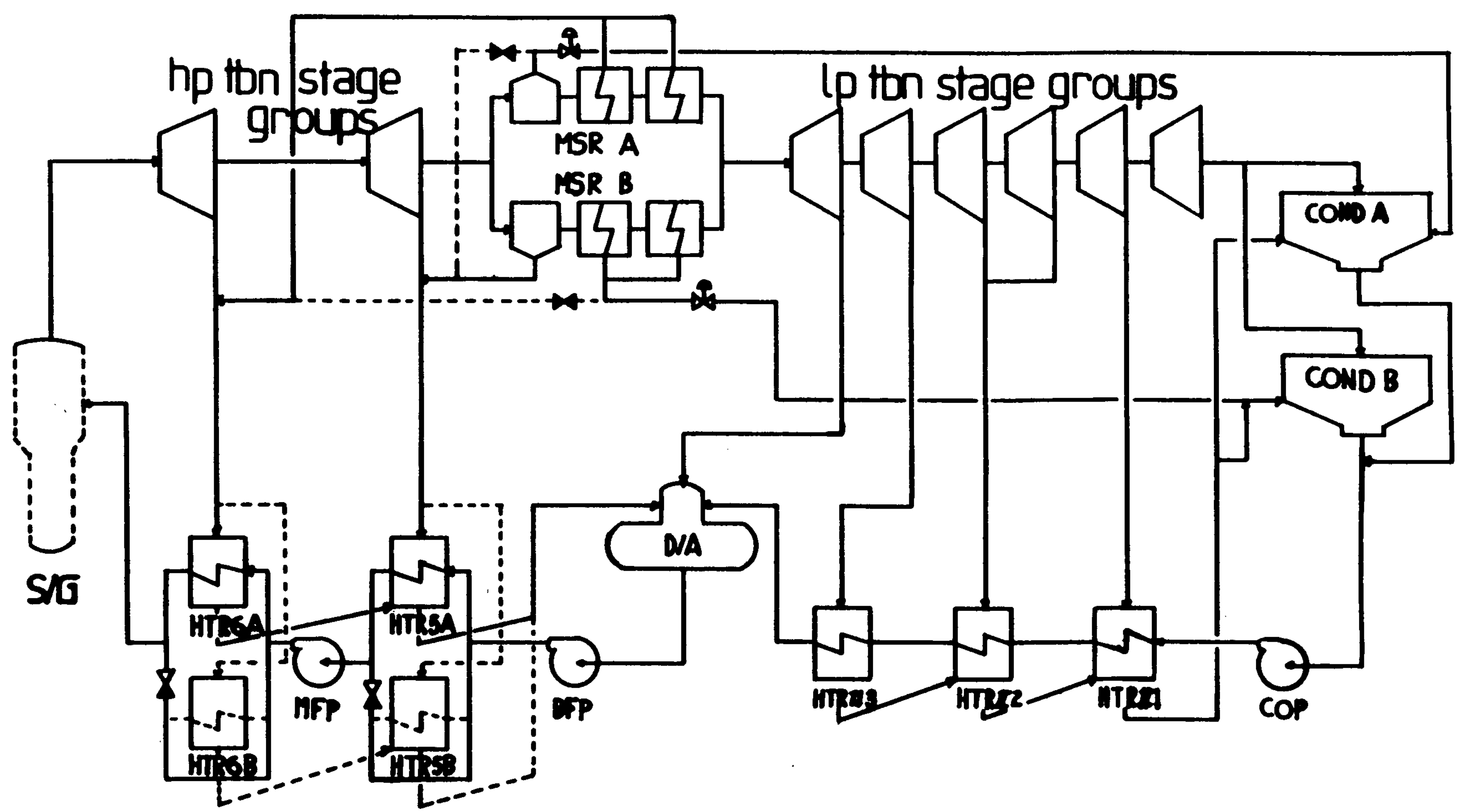

Fig.2 Geometrical Modeling of the HP Feedwater Bypass Operation

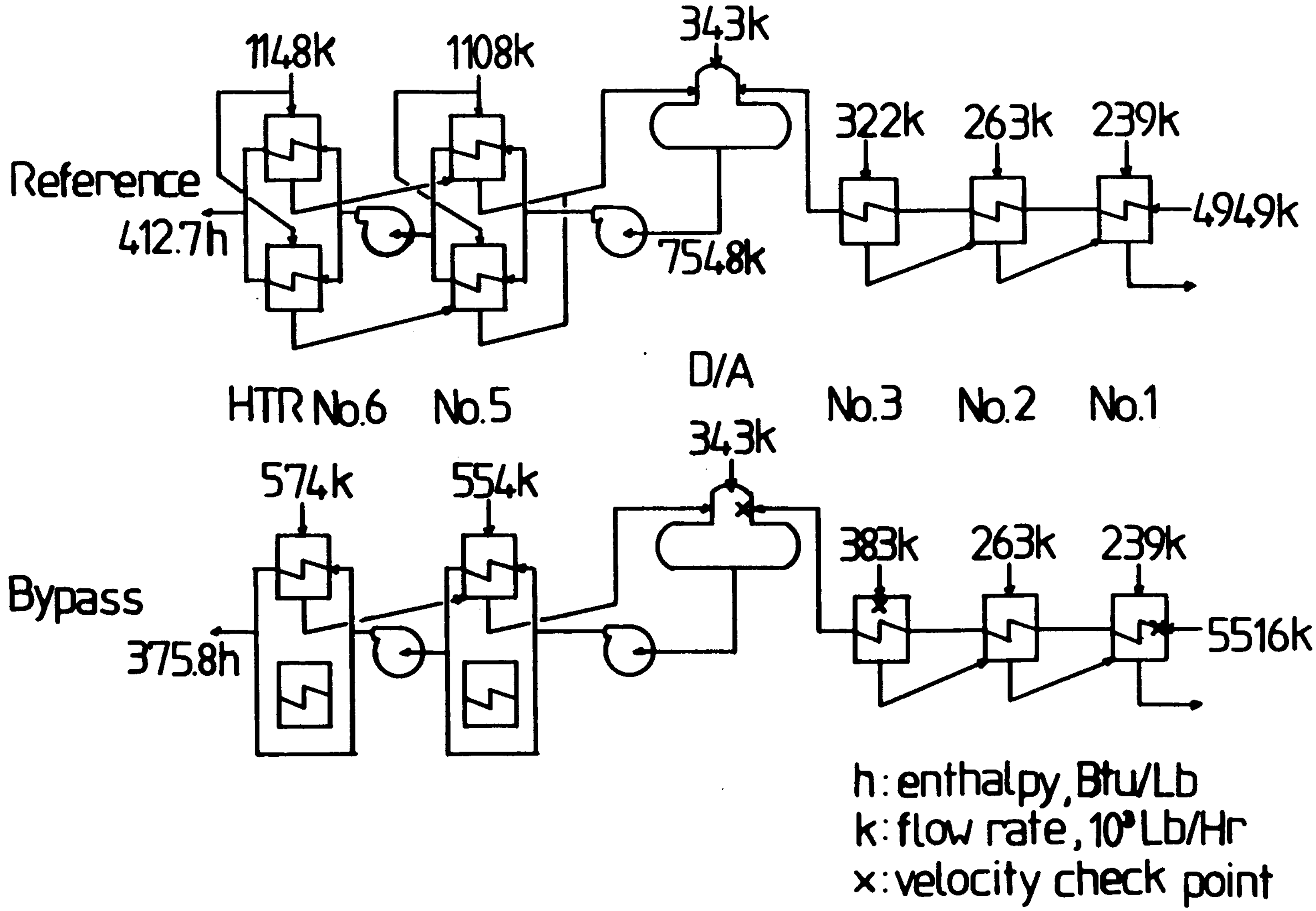

Fig. 3 Flow Deviation in Feedwater Side

Table 1. Major Performance Parameters

Parameters / Unit / Case	TBN Power	Rx Power	Eff.	Heat Rate	Main Steam		S/G Feed-in Enthalpy	Remarks
					Flow Rate	Enthalpy		
	MWe	MWth	%	Btu/KWh	10^6 Lb/Hr	Btu/Lb	Btu/Lb	
Design	595.0	1725.8	34.45	9908	7.51	1197.6	412.7	
Reference	593.8	1730.0	34.32	9944	7.51	1198.8	412.7	PEPSE run
Bypass	580.3	1676.0	34.46	9856	6.95	1198.8	375.8	
	(-2.3)	(-2.9)	(+0.4)	(-0.9)	(-7.5)	(-)	(-8.9)	

( ) : % change of Bypass data to Reference

Table 2. Effectiveness of Feedwater Heaters

Case\Heater	No. 1	No. 2	No. 3	D / A	No. 5	No. 6
Reference	0.941	0.983	0.998	0.656	0.955	0.977
Bypass	0.997	0.952	0.935	0.790	0.825	0.931