PNC TN9410 91-028

# ANALYSIS OF LARGE LEAK SODIUM-WATER REACTION IN LARGE FBR

January, 1991

OARAI ENGINEERING CENTER

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION

PNC TN9410 91-028
January, 1991

# ANALYSIS OF LARGE LEAK SODIUM-WATER REACTION IN LARGE FBR

Hiromi TANABE and Hirotsugu HAMADA

Power Reactor and Nuclear Fuel Development Corporation
O-arai Engineering Center
4002 Narita, O-arai, Ibaraki, Japan

## ABSTRACT

A computer code, SWACS, was developed to analyze a large leak sodium-water reaction event in an LMFBR steam generator. The Japanese prototype reactor, Monju, has a cover gas space in its steam generator but different designs are also considered for a future larger plant. Therefore, SWACS was modified to analyze the sodium-water reaction event under such various designs. So far the calculational module of an initial spike pressure and its propagation to IHTS was improved and the results were compared with the data from LLTR at ETEC, U.S.A. and water-explosive simulation tests at PNC, Japan. The comparison revealed a fairly good agreement between the tests and the analyses. Following the validation study, SWACS was used for the application analysis to compare the pressure behavior between the cover-gas type and the no-cover-gas type steam generator of a future larger plant. The analysis clarified the applicability of SWACS to such a design study from a viewpoint of suppressing the SWR pressure.

## 1. INTRODUCTION

SWACS (Sodium-Water Reaction Analysis Code System)$^{1)}$ is an integrated computer code to analyze pressures and fluid flow phenomena in an intermediate heat transport system(IHTS) including a steam generator (SG) in a large-scale sodium-water reaction (SWR) event. SWACS consists of three modules to calculate a water leak rate, the initial spike pressure (ISP) and its propagation through the IHTS piping, and a quasi-steady pressure. In a recent design study for a larger FBR plant, a non-cover gas type SG is considered as one of the promising designs from a viewpoint of plant cost reduction. In this type of SG, however, the ISP and its propagated pressure might be higher than those in a cover gas type SG because of the lack of the fluid-gas interface which behaves as an effective pressure wave absorber. Therefore, two new calculational models have been added to SWACS to analyze the ISP behavior more precisely for this type SG; the dynamic response model of an in-sodium rupture disk using FEM and the fluid-flow model using BTM (Boundary Tracking Model) in the pressure relief piping. This paper describes these new models, together with their validation and application studies of the SWACS code.

## 2. DEVELOPMENT OF NEW MODELS

### 2.1 Rupture Disk Response Model

In the non-cover-gas type SG design, in-sodium type rupture disks should be installed directly to the SG or to the main piping near the SG so as to sufficiently release the pressure. The ISP generated by SWR propagates through the SG (and the main piping) and reaches the rupture disk. At the rupture disk surface, the high frequency pressure waves partially reflect on the disk and partially cause the deformation of the disk. Since the interaction between fluid and the disk may give an important effect on the pressure behavior during and after the bursting, SWACS has to take the fluid-disk interaction into account in its disk bursting model. The rupture disk response model integrated into SWACS had been developed originally as a subprogram of SWAAM-I$^{2)}$ by ANL, U.S.A., and was exchanged for SWAC-13 of PNC between USDOE/JAPAN. In the old version of SWACS before the integration of the dynamic response model, the rupture disk was dealt with as a rigid end until the fluid pressure exceeded a certain preset value. Then once the pressure exceeded the preset value, it was instantaneously handled as an open end.

The new model calculates disk deformation using FEM by taking account of the the fluid-disk interaction. The deformed disk starts to tear after the displacement of a disk center exceeds a certain value. A double-membrane rupture disk assembly consists of two disks between which compressible gas is contained. Then in the double-membrane disk model, not only the interaction between the first disk and sodium, but also the deformation and bursting of the second disk should be considered because the sodium rushes into the gas space after the opening of the first disk and the second disk undertakes a pressure load from the gas compressed by the moving sodium head.

### 2.2 Boundary Tracking Model

For the calculation of ISP and its propagation through the IHTS piping, a simplified method of characteristics was applied to SWACS except the bubble growth model in the reaction zone. The simplified method denotes the FBM (Fixed Boundary Model) that the fluid-gas interface is time-independently fixed at a certain nodal point in the piping. On the contrary, a new method of characteristics using the BTM is applied to SWACS. In the BTM, the fluid-gas interface moves along the stream lines of the piping; then the physical properties such as velocities and pressures are calculated more precisely at the fluid-gas interface and any nodal points. Thus, the BTM can reduce numerical errors even though it needs more complicated calculational process. The BTM is especially useful in the pressure relief piping between the rupture disk and a dump tank because the sodium head moves there quickly along the line after the disk bursts.

## 3. CODE VALIDATION

Following the completion of the code modification, experimental data became necessary to validate the modified SWACS code. The data were obtained from LLTR (Large Leak Test Rig), U.S.A. and water-explosive tests named PEPT (Pressure Effluence Performance Test) conducted by PNC.

### 3.1 LLTR tests and analysis

LLTR is a large-scale SWR test rig which was constructed at Energy Technology Engineering Center (ETEC) by USDOE to demonstrate the integrity of CRBR's SG. Since the CRBRP SG was a non-cover-gas type, the test data was suitable for the SWACS validation study. Test A-2 of the LLTR series II performed in 1980 was a DEG (double-ended guillotine failure) scale SWR test with a double membrane rupture disk on the lower piping connected to the reaction vessel as shown in Figure 1. The rupture disk had two 2.3 MPa diaphragms of 18 inches (0.46 m) in diameter.

A computational network model of Test A-2 is shown in Figure 2. The model consists of 41 joints and 40 members, where the circle and the line between two circles denote the joint and the member, respectively. J(oints)-1 through 14 correspond the reaction vessel, i.e., the simulated SG. J-3, 19, and 20, and M(ember)-19 correspond to a leak site, the rupture disk, a reaction product storage tank, and the pressure relief piping, respectively. Test data measured by a turbine-flowmeter were tabulated and used for the input values of a water leak rate.

A pressure history at J-19, just before the rupture disk, is presented in Figure 3, where the bold line and the fine line respectively denote test data and calculated results. In the experiment, after the first disk had burst at about 8 msec, the pressure decreased with fluctuations and the pressure gradually began to increase again at about 50 msec and had its peak at 65 msec by the second disk bursting. The calculated failure time of each rupture disk is about 9 and 60 milliseconds for the first and the second disk, respectively. The maximum pressures are also close such as 30 and 25 $kg/cm^2$ (2.9 and 2.5 MPa) in the test and in the analysis, respectively. Although the analytical results slightly overestimated the pressure in the time region between the first and the second disk bursting, the overall agreement is excellent between the test and the analysis.

The analytical deformation profiles of each disk are shown in Figure 4. It should be noted that the first disk begins to deform at the disk center whereas the second one deforms uniformly. This is due to the difference of interacting fluids; sodium and gas.

### 3.2 PEPT tests and analysis

The PEPT facility was constructed in 1988 to simulate the ISP propagation phenomena in a large-scale SWR event using water and explosives. Key characteristics are as follows:

1. 1/5 scale model of a 1000 MWe class future plant design.
2. Flexibility to vary a system configuration in accordance with the plant design to be demonstrated such as:
   (1) cover gas space can be installed or removed.
   (2) pressure relief line formation can be changed.

Two series of tests were performed from 1988 to 1989. In Series 1, more than 30 tests were conducted by varying the formation of main components and pressure relief piping. In Series 2, 10 tests were carried out with/without the double rupture disk unit varying its design dimensions. In Test SB41 of Series 1, the loop consists of a simulated SG, an IHX (intermediate heat exchanger), a mechanical pump and piping connecting these components one another as shown in Figure 5.

Figure 6 shows a computational network model of Test SB41. It consists of 35 joints and 35 members. J-10 through 19, J-2 through 4, and J-26, 27 and 35 modeled the SG, the IHX, and the pump, respectively. The pressure measured near an epicenter in the test was used as a source pressure of J-17 in the calculation.

Figure 7 shows the pressure histories at J-17, 19, 9, and 3 corresponding to the pressures of the source, hot leg piping, cold leg piping, and the IHX, respectively. In the cold leg piping, the agreement of the peak pressure is fairy good in spite of minor underestimation. In the IHX, though a rapid pressure increase occurs slightly earlier in the calculation than that of the test, the peak pressure and the pressure shape qualitatively show a good fitting. The comparisons between the test and the calculation generally give a good agreement and indicate obviously that the code can calculate the pressure propagation through the piping even for the non-cover gas type SG system.

## 4. APPLICATION ANALYSIS

Since above stated modification made SWACS applicable to various designs, a design study for a future larger plant was carried out by use of SWACS. Here, an example of application analysis is presented for the future plant of around 1000 MW of electricity. Figure 8 shows a schematic image of a conceptional plant with non-cover-gas type SGs where the gas space to absorb sodium volumetric change is located in a pump instead. The SG is helically coiled unit type generating 650 MWt. On the other hand, the corresponding cover-gas type SG was also designed by moving the cover-gas space from the pump to a top of SG.

In the analysis, a 1-DEG water leakage is postulated to occur in a lower tube bundle region. The assumed water leak rate is initially about 35 kg/sec and decreases to 10 kg/sec at 200 msec. The analytical results are shown in Figure 9 where broken line and bold line denote the IHTS pressures in the cover-gas type and the non-cover-gas type, respectively. Due to the lack of absorption effect on sodium free surface in the SG, the pressures in the hot-leg piping and the IHX of the non-cover-gas type are much higher than those of the cover-gas type design. In the cold-leg piping, however, the pressure of non-cover-gas type is slightly lower because of the free surface effect of the pump. Although these analyses quantitatively clarified that the pressures in the non-cover-gas type was generally much higher than those in the cover-gas type, other beneficial information was also obtained. For example, the pressure even in the non-cover-gas type SG could be decreased efficiently by the adequate designing of the pressure relief line such as shortening the distance between the rupture disk and the main piping or installing the rupture disk directly to the SG.

## 5. CONCLUSIONS

A dynamic response model of the in-sodium type double-membrane rupture disk and the accurate BTM method were added to the SWACS to make it applicable to various types of SGs. The analytical results using the new code were compared with the test data of LLTR and PEPT. The comparison resulted in a fairly good agreement. As a result of application to a future larger plant, some understandings were obtained concerning the SG designing from a viewpoint to suppress the SWR pressure.

## REFERENCES

1. O.MIYAKE, et al,"Large Leak Sodium-Water Reaction Code SWACS and its Validation", LMFBR Safety Topical Meeting, Lyon, France, 1982, July

2. Y.W.SHIN, A.H.WIEDERMANN, T.V.EICHLER, C.K.YOUNGDAHL and C.E.OCKERT, "An Analytical Model for Dynamics of a Sodium-Water Reaction Bubble in an LMFBR Steam Generator and the Coupled Response of the Intermediate Heat Transport System", Nuclear Engineering and Design 106(1988)

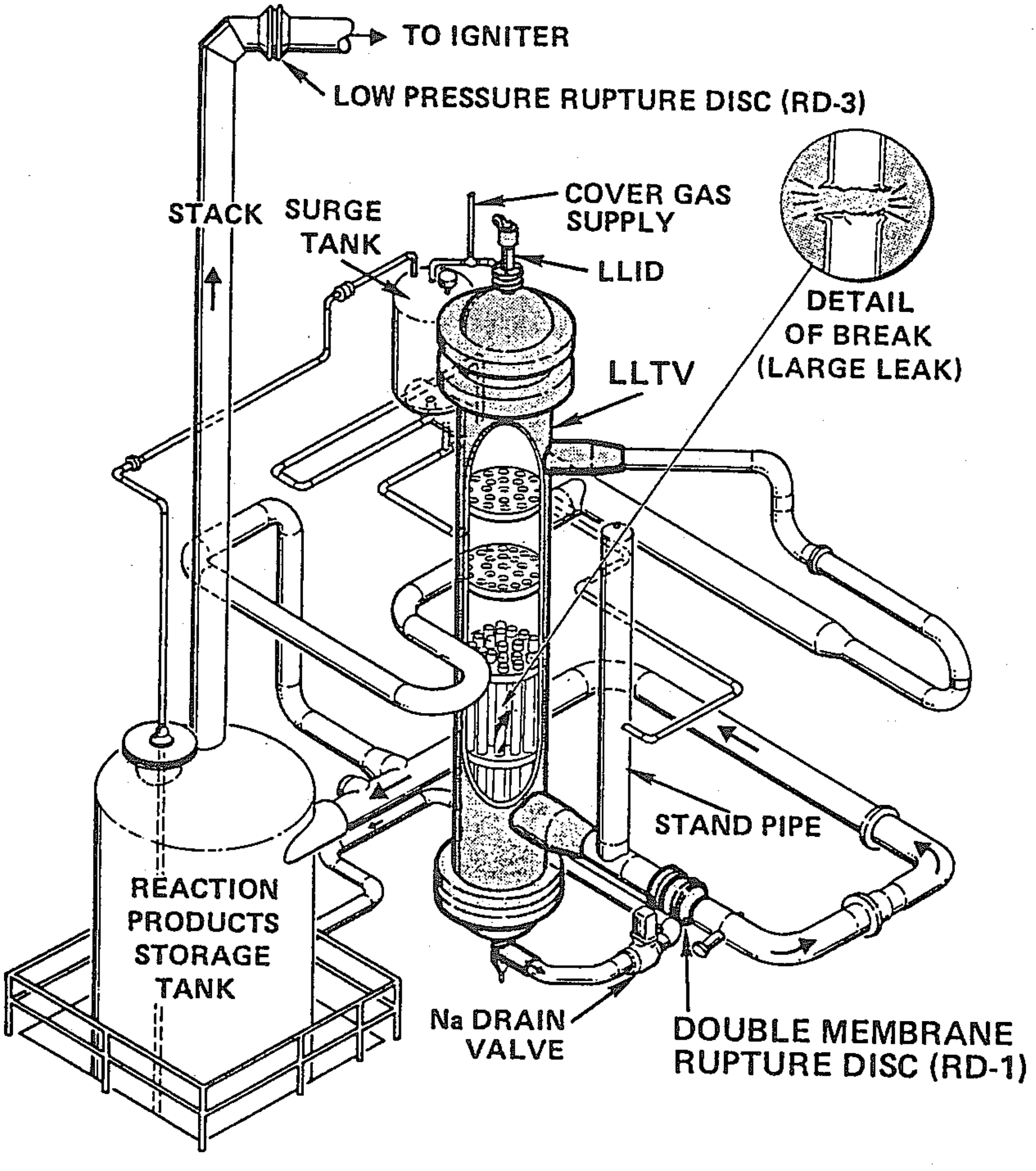


Figure 1 LLTR Test Rig

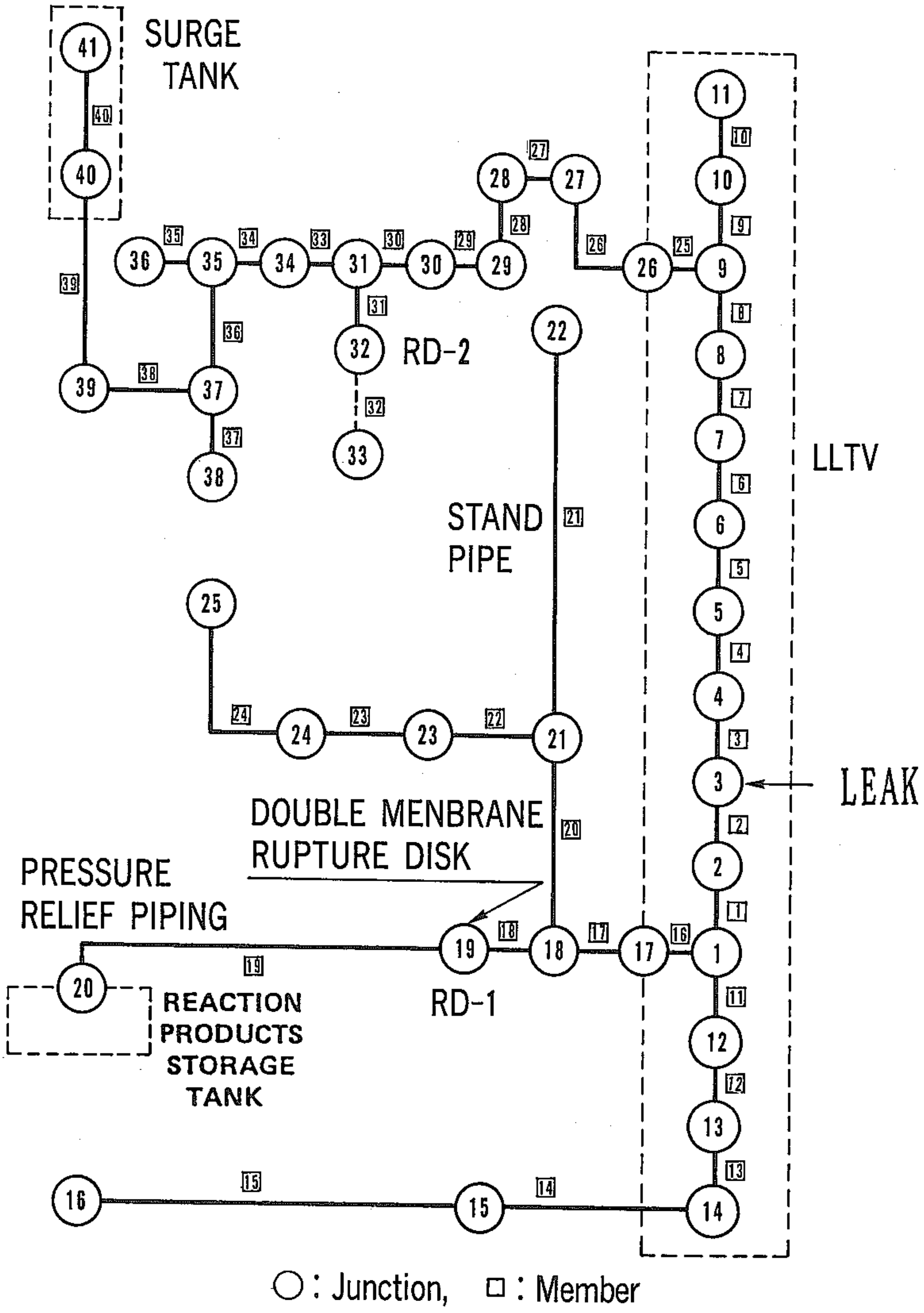


Figure 2 Computational Net-Work Model of LLTR Test A-2

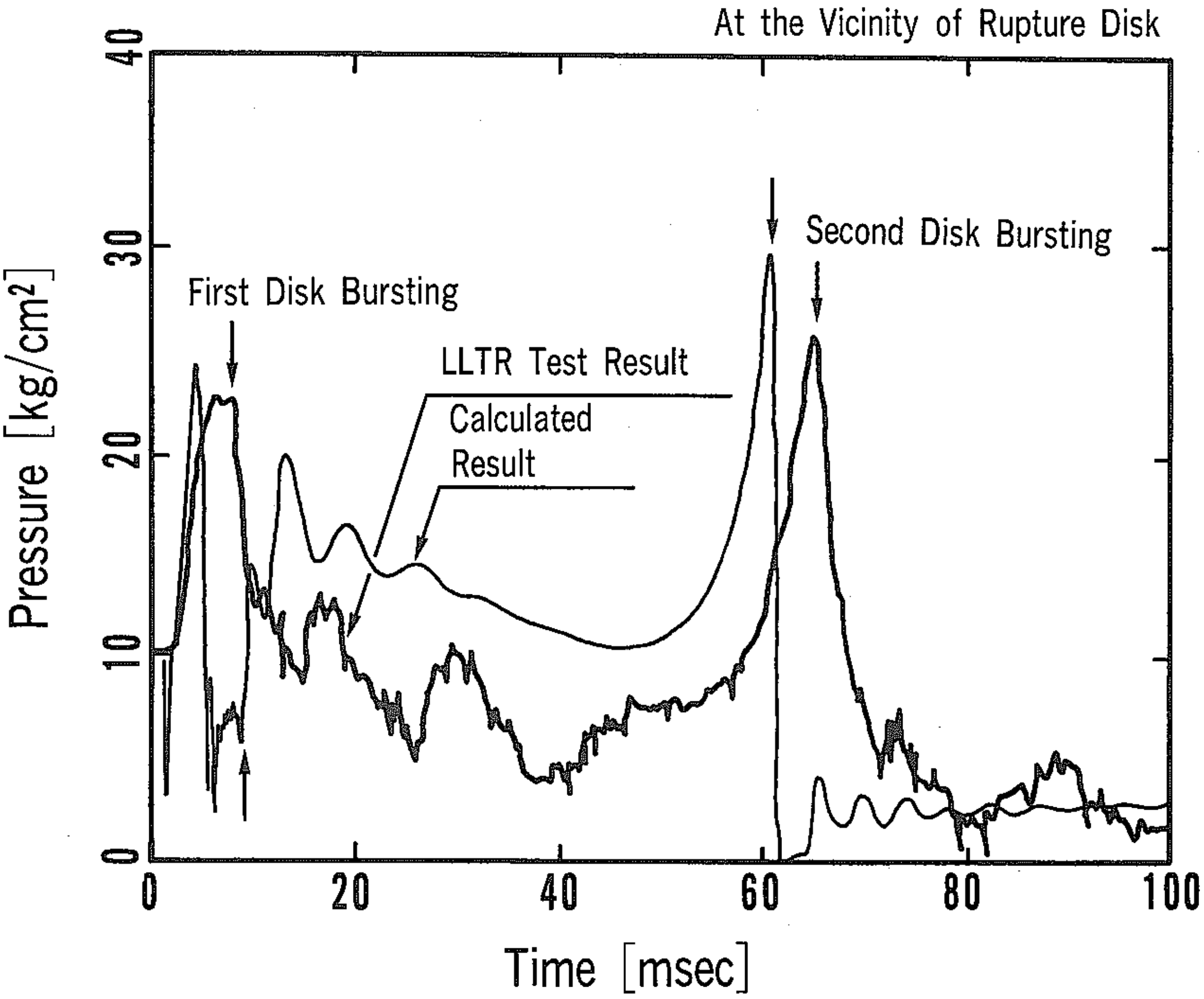
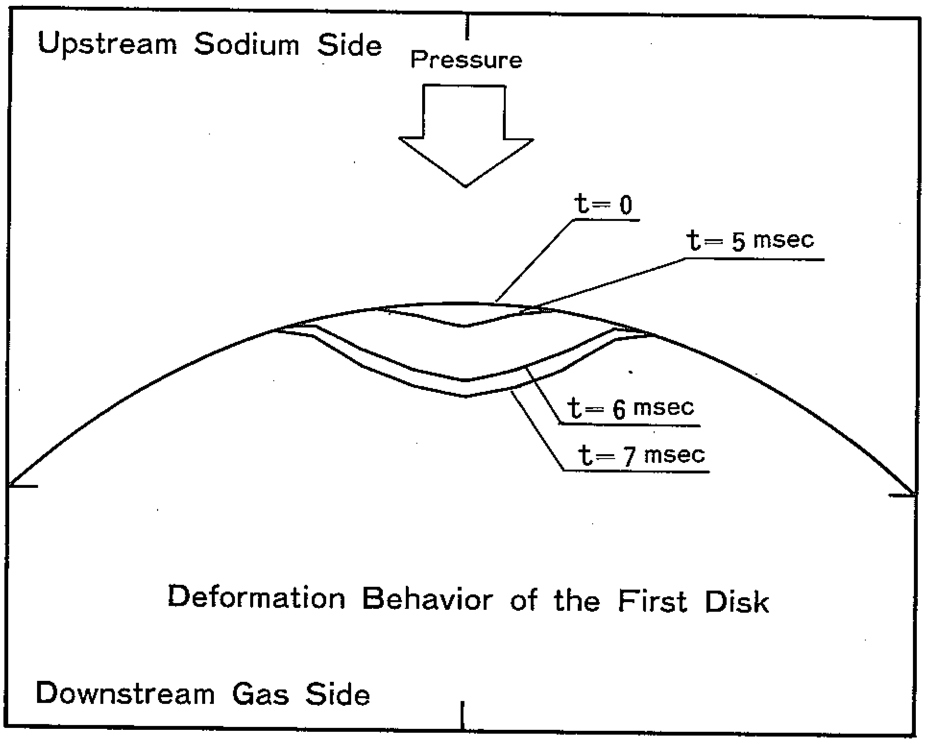


Figure 3 Pressure History just before the Rupture Disk



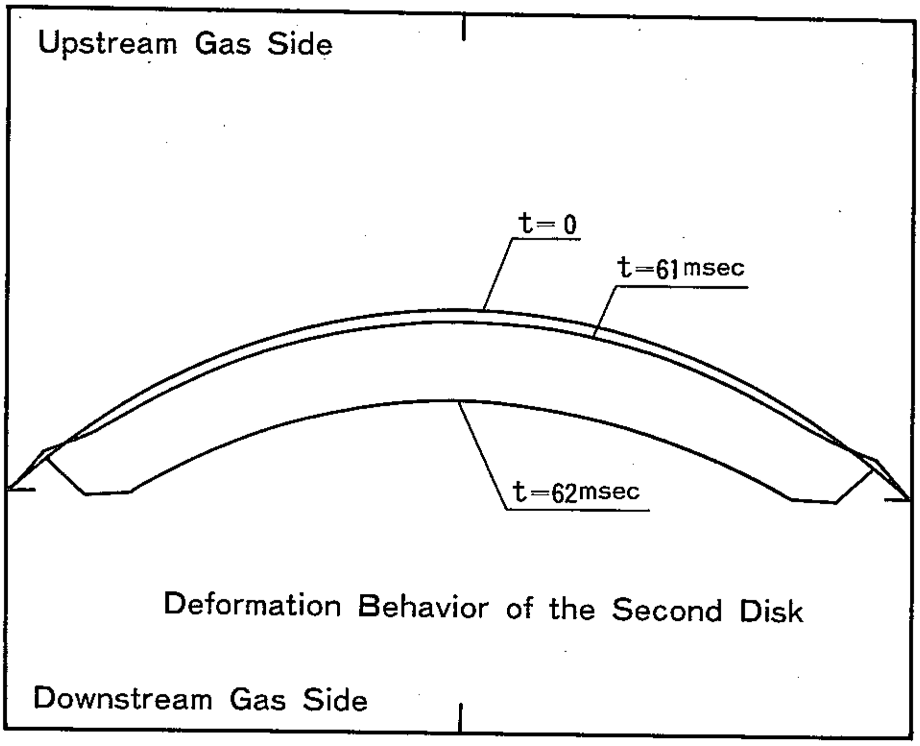


Figure4 Behavior of Rupture Disk Deformation

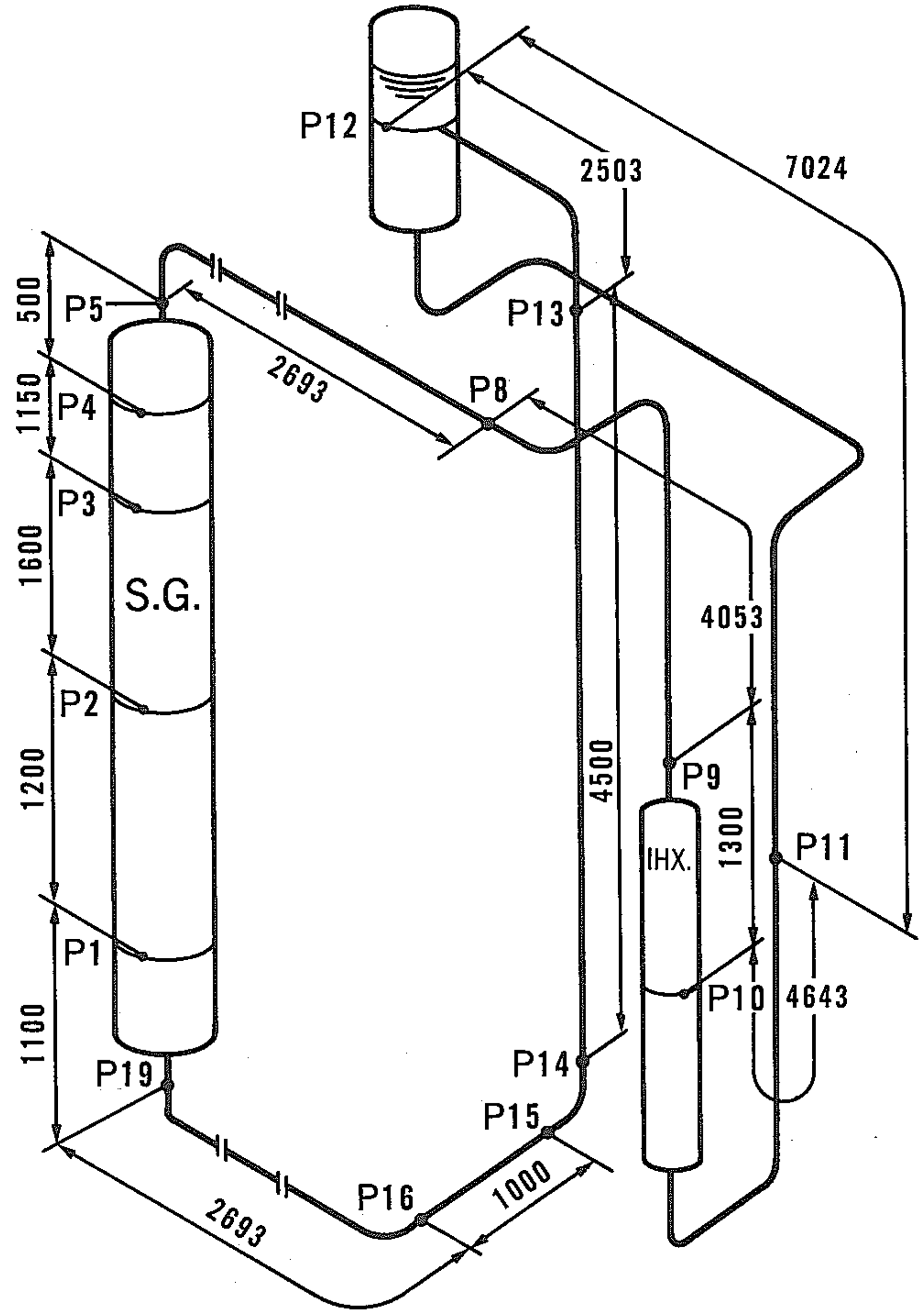


Figure 5 PEPT Test Rig

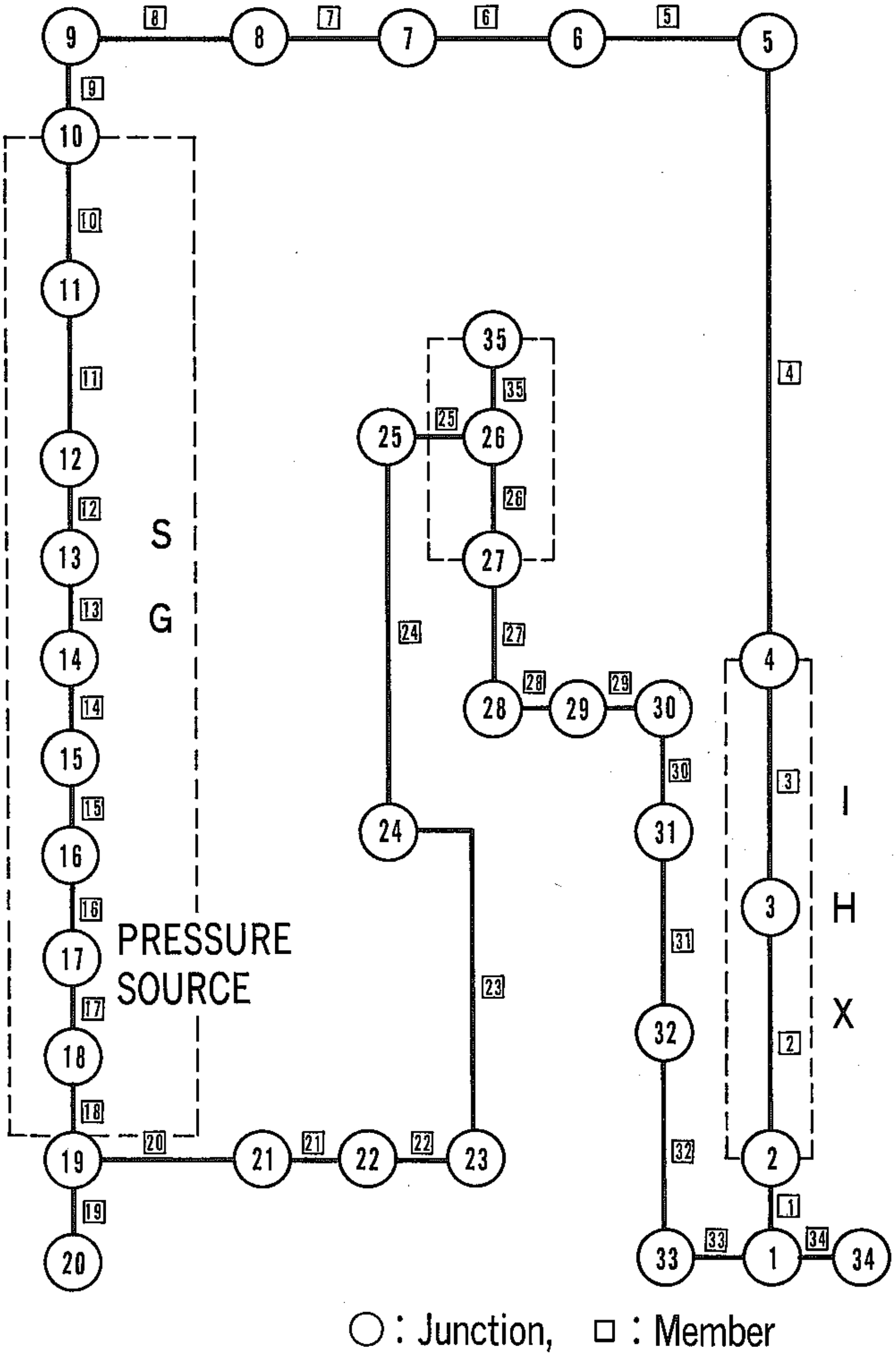


Figure 6 Computational Net-Work Model of PEPT SB41 Test

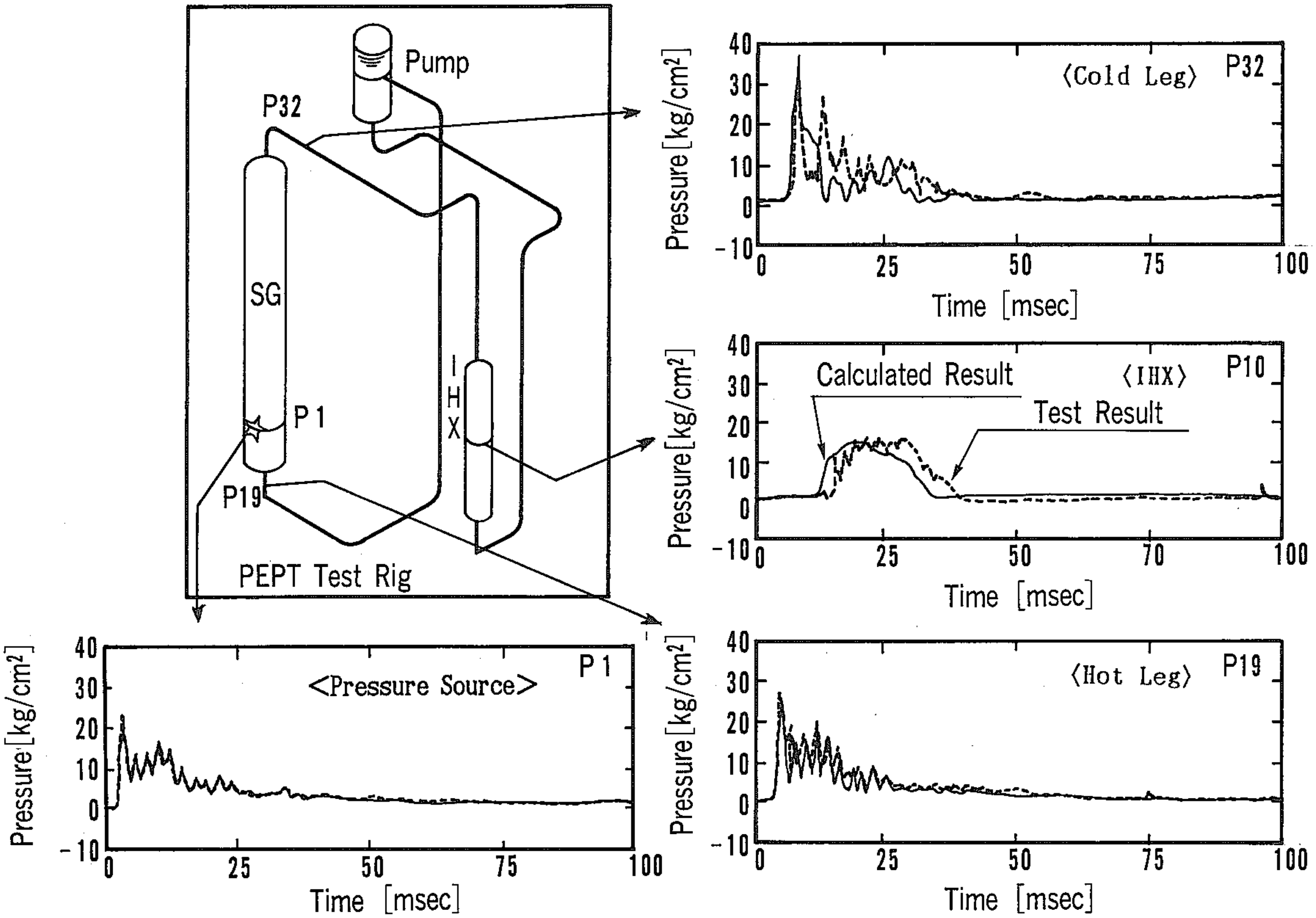


Figure 7 Pressure Histories at Cold-Leg Piping, Hot-Leg Piping, and IHX

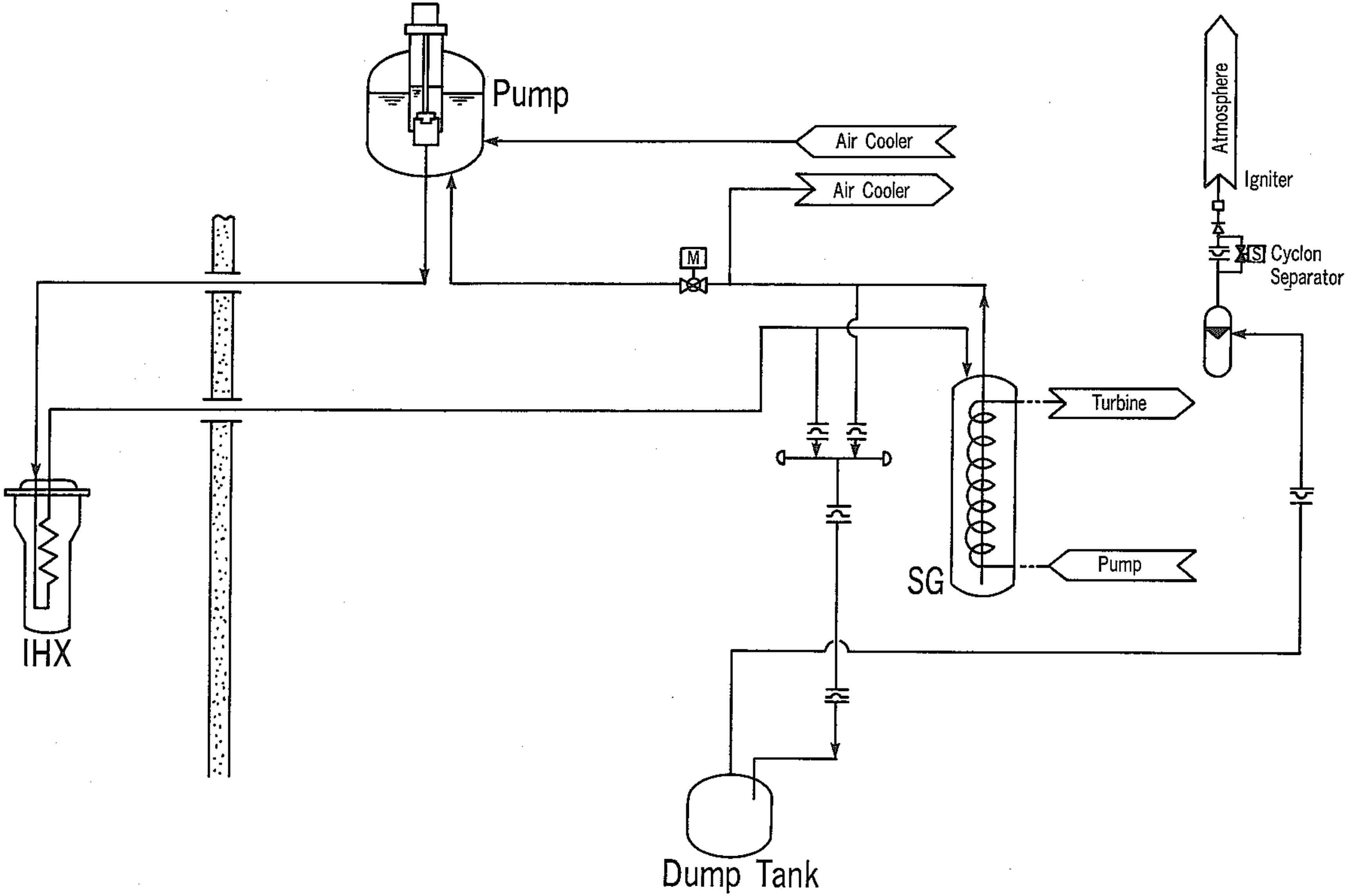


Figure 8 Intermediate Heat Transport System of a Large FBR Plant.

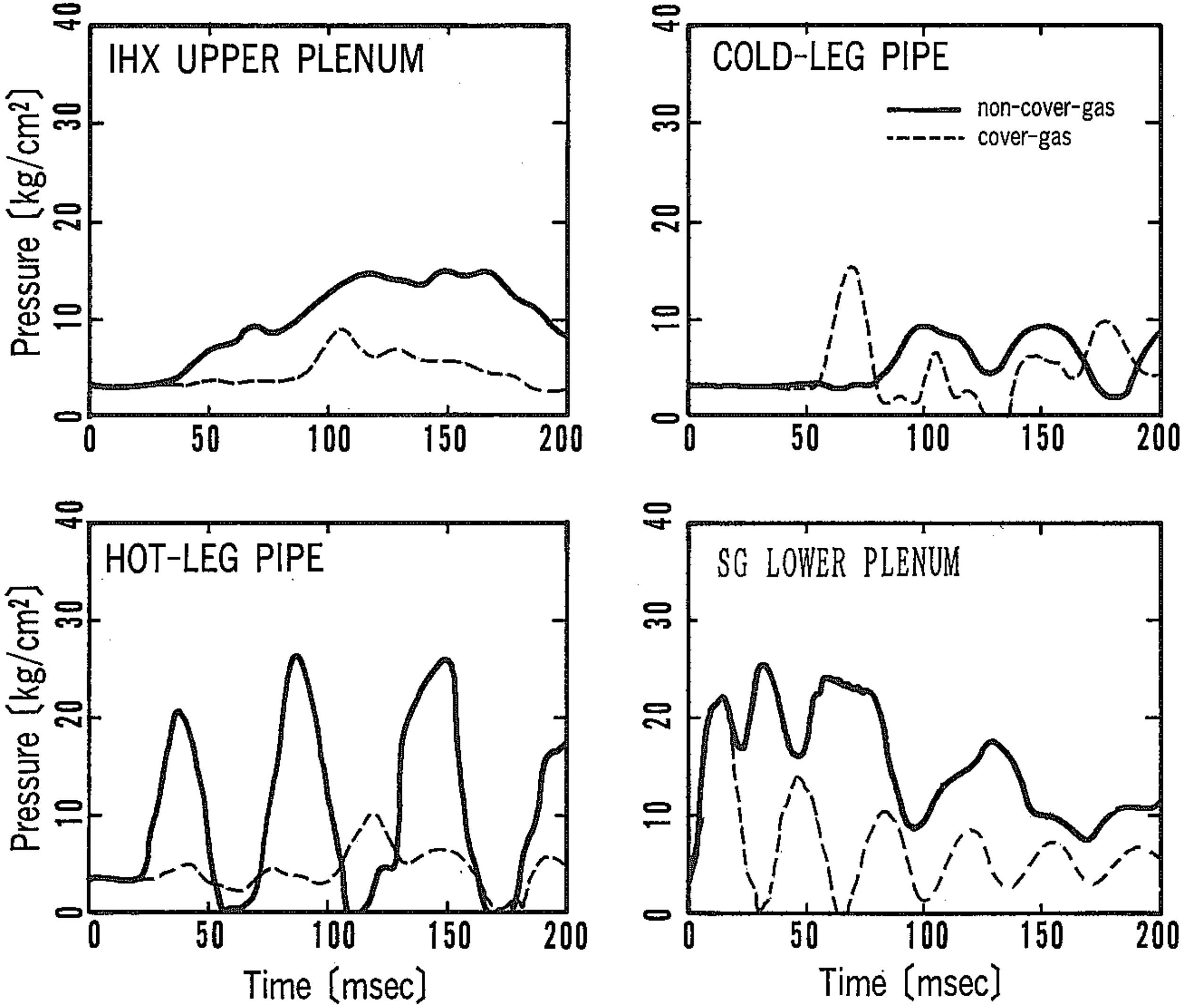


Figure 9 Comparison of Pressure Behavior between Cover-Gas Type and Non-Cover-Gas Type SG