BWR WATER-LEVEL BACKFILL MODIFICATION EVALUATION USING RELAP5

Joseph S. Miller
SCIENTECH, Inc.
11140 Rockville Pike, Ste 500
Rockville, Maryland 20852

Alex Klemptner
Detroit Edison Company
6400 N. Dixie Highway
Newport, MI 43166

Jim Morgan
SCIENTECH, Inc.
11140 Rockville Pike, Ste 500
Rockville, Maryland 20852

1. INTRODUCTION

When the Nuclear Regulatory Commission (NRC) issued a bulletin requiring implementation of a backfill modification at all boiling water reactors (BWRs), the Detroit Edison Company (DECo) decided to take a proactive approach and thoroughly test the modification before implementing it at its FERMI-2 nuclear power plant.

DECo built a testing facility separate from the plant to simulate transient events and later hired the technical services consulting firm, SCIENTECH, Inc., to evaluate the associated test configuration and testing results. As a result of this extra effort, DECo was able to identify some potential problems posed by the modification and institute adequate solutions even before the modification was operative.

In evaluating DECo's test results, SCIENTECH performed RELAP5 computer simulations to validate the transient and steady state characteristics found in the test results. RELAP5 studies also were performed to determine the effectiveness of installing pressure attenuators in the backfill modification.

II. BACKGROUND

NRC Bulletin 93-03, dated May 28, 1993, requires all Boiling Water Reactor (BWR) licensees to modify their reactor water-level measurement systems to ensure gas-free cold reference legs. To comply with the bulletin, Detroit Edison designed and implemented for testing a water-level backfill modification. As part of the modified acceptance criteria, DECo conducted tests to ensure that the design requirements were satisfied, making use of Boiling Water Reactor Owners Group (BWROG) recommendations on testing and design implementation [1,2]. During the review of these test results, some instrumentation anomalies were identified and subsequently analyzed to determine their significance.

III. SUMMARY

NRC Bulletin 93-03 requires all BWRs to modify their reactor water-level measurement systems to ensure that their reference legs remain full following depressurization, whether rapid or slow.

In all BWRs noncondensable gases are created by the radiolytic breakdown of the water molecule. Some portion of these gases migrates to and accumulates in the reactor water-level condensing chambers. These gases become dissolved in the chamber/reference leg water. Molecular diffusion and mechanical movement, as created by small leaks at the instrument racks, allow these dissolved gases to saturate the entire reference leg. Upon depressurization, whether rapid or slow, these gases can come out of solution and displace reference leg inventory, resulting in a nonconservatively high water-level indication.

To deal with this problem, the BWROG developed a modification called the water-level backfill system, which provides a continuous flow of essentially de-aerated water into the reference leg from the control rod drive (CRD) system, thus keeping the reference leg purged of dissolved gases. Due to limiting conditions of operation, DECo tested the backfill modification off-line, which involved using specially built apparatus to simulate differential pressures across level transmitters.

When DECo tested this new configuration the results indicated some anomalies that required further evaluation. This paper provides the results of this review. The Division I backfill water-level test configuration is shown in Figure 1. Computer analyses using RELAP5 were performed to validate the evaluation.

The evaluation process consisted of reviewing and analyzing the CRD interface, reviewing and analyzing the water-level modification, and reviewing and analyzing the test configuration. To simulate plant fluid transients, DECo-SCIENTECH used the computer program RELAP5 to develop a hydraulic model of the FERMI-2 plant backfill modification. RELAP5 is a computer program used worldwide to simulate transient events.

Two primary tests were reviewed. The first test set was performed to determine the impact on the backfill modification during reactor pressure vessel (RPV) depressurization and the second test set was performed to determine the impact on the backfill modification due to pressurization and depressurization in the CRD system. DECo-SCIENTECH used RELAP5 to analyze each of these tests.

The results of the first test set analysis indicated that the anomalies were caused by depressurizing the test apparatus. This apparatus produced significant water-level perturbations during testing, especially when the nitrogen pressure was being reduced in step pressure changes. During this depressurization event the water-level instruments registered significant oscillations. These oscillations, however, were found to be caused by the hydraulic responses of the test apparatus and by the gas acoustics and would not occur during normal plant operations. This qualitative evaluation was validated by performing a quantitative evaluation using RELAP5. In addition, a computer simulation using RELAP5 of the actual water-level backfill modification to be installed in the plant indicated no anomalies. Thus DECo-SCIENTECH concluded that the pressure anomalies observed during the RPV depressurization testing were not due to the backfill design.

The second test set analyzed was that of CRD pressure fluctuation. As shown in Table 1, two types of events can cause such fluctuations at a water-level transmitter. The first is a CRD pressurization event, characterized by the CRD pump start, scram, and individual rod scram events. DECo-SCIENTECH simulation of these events produced a negative pressure differential at the transmitter followed by a positive pressure differential. The second type of event that can cause CRD pressure fluctuation is the depressurization event, which causes the check valve to close and which occurs during the CRD pump trip. Such events produce a positive pressure differential at the transmitter followed by a negative pressure differential. The BWROG recommended that attenuators be used to reduce pressure pulses from the CRD system. The effectiveness of attenuators in countering the consequences of pressurization or depressurization events is limited because the attenuators only change the pressure and flow upstream of the check valves. These variables directly influence the timing of the check valve closure.

IV. COMPUTER ANALYSIS OF TEST APPARATUS FOR RPV DEPRESSURIZATION

Using the computer program RELAP5, SCIENTECH developed a hydraulic model to verify the qualitative analysis of Data Set 9-6-6-3. The model was structured based on test rig simulator and backfill system tubing lengths and diameters, test cylinder capacity, and mass flow rates required to achieve similar pressure profiles as depicted in the test data. Basically, the first pressure step change and the subsequent pressure decay for Data Set 9-6-6-3 were duplicated and analyzed. Because the whole test was merely a sequence of pressure step changes, analysis of one step change and pressure decay was considered sufficient for purposes of verification.

The main objective of the analysis was to see if the transient characteristics could be reproduced analytically. The model was able to produce very similar transient level profiles, not only in shape, but in order of magnitude for both level deviation amplitude and elapsed time.

A RELAP5/MOD3 dynamic simulation of the FERMI-2 water-level instrumentation tests was performed. All major components of the FERMI-2 test rig were simulated in the RELAP5 model. The RELAP5 simulation was undertaken not to reproduce the test results but to gain an understanding of the fluid dynamics occurring during selected segments of the test. The results from the RELAP5 simulations showed that the observed testing anomalies were a function of how the test was run.

In conclusion, the computer simulation verified that the transients would not occur during normal plant operations. The test rig produced certain levels of perturbations attributable to the dynamics of nitrogen supply pressure.

V. CRD TESTING AND RELAP5 RESULTS

The CRD pressure transients were simulated with RELAP5 primarily to establish the cause of the water-level variation observed during testing. Figure 2 shows a noding diagram of the RELAP5 model, which was set up for the backfill system test apparatus. The endpoints of the HCU pipe and at the condensing chamber are represented by time dependent volumes. Initially, the condensing chamber was at a pressure of 1050 psia; the HCU piping was at a pressure of 1450 psia. Five pipe components connected by single-junction components or valve components represented the tubing run, including the pressure regulator, needle valve, and check valves.

The check valves were modeled using the RELAP5 motor valve component. Trips were included to open the valve when the differential pressure across the check valve exceeded 0.33 psi and to close when the differential pressure dropped below 0.20 psi. These values were selected to keep the valve open during the initialization portion of each run during which a steady flow was established. Closing characteristics were modeled by varying the stroke time of the valve between 1 and 10 milliseconds. A strong check valve spring represented the 1ms closure and a weaker check valve spring represented the 10 ms closure. The intent was to develop a pressure fluctuation with frequency characteristics similar to those observed in the test data.

The model was first run with a depressurization of the CRD header from the initial 1450 psi to 900 psia over a .0001 second period. This was the run without attenuators. To determine the pressure fluctuation mitigation effect of attenuators in the line, the model was modified to add three sample cylinder attenuators.

Each of the attenuators was set up to approximate a Whitney-NUPRO sample cylinder with an ID of 1.814 inches and a flow area of 1.795E-2 ft^2 . The length of the cylinder section was 5 inches. The inlet and outlet had flow orifices with 0.25-inch diameters (flow area of 3.409E-4ft^2). In the model with attenuators, a total of three attenuators was included, one upstream of the pressure regulator and two downstream of the needle valve. To include the attunuators, components 101 and 103 were modified to each have 23 nodes. Runs were made with and without the RELAP5 abrupt area change model option for the attenuators. This option did not affect the simulated responses.

A second RELAP5 model was developed to represent a CRD pressurization event. This event was simulated by ramping the pressure in component 301 from 900 psia to 1450 over a .001 second period. From this evaluation it as determined that pressure transients from the CRD system could be seen by the transmitters as water-level changes.

Two events were characterized as CRD transients. The first type was a CRD pressurization event, which produces a negative pressure differential at the transmitter followed by a positive pressure differential. The second type is a depressurization event, which causes the check valve to close. Depressurization events are characterized at FERMI-2 by the CRD pump trip and the scram. As seen in Table 1, a depressurization event in the CRD system can cause as much as 14 inches of variation in the water-level indication and a pressurization event in the CRD system can cause an 8-inch variation in the water-level indication. To reduce these measured water-level variations, the use of attenuators was simulated using RELAP5.

Attenuators influence such events in different ways. During a pressurization event, the added attenuators affect the pressure wave directly as it travels to the transmitter, whereas during a depressurization event the added attenuators affect the check valve closure, which causes a wave to travel to the transmitters. Direct attenuation of the pressure pulse during a pressurization event is more effective (with a 56% reduction in the pressure change at the transmitter) than it is during a depressurization event (with a 36% reduction in the pressure change at the transmitter). The effectiveness of the attenuators in response to depressurization events is limited because the attenuators only change the pressure and flow upstream of the check valves. These variables directly influence the timing of the check valve closure. In turn, the timing of the valve closure reduces the magnitude of the pressure wave that is produced downstream as a result of the check valve closure.

VI. CONCLUSIONS

The DECo-SCIENTECH review of the first test set, which was to determine the impact of RPV depressurization on the backfill modification, demonstrated that the perturbations observed in the results of the earlier conducted tests were artifacts for the test apparatus and would not be seen when the backfill modification was installed in the plant.

The DECo-SCIENTECH review of the second test set, which was to determine the impact of CRD system pressurization and depressurization on the backfill modification, led to the following conclusions and recommendations. The CRD pressure disturbances caused several significant pressure differentials (8 inches or greater) at the transmitter. This can be seen in Table 1. To respond to this disturbance, DECo-SCIENTECH recommend that at least two attenuators be placed downstream of the needle valve to help reduce CRD pressure transient responses to the water-level transmitter. RELAP5 simulations demonstrated that these attenuators will reduce the pressure oscillations by at least 36%.

To attenuate the dominant low-frequency responses (i.e., 5 Hz) seen at the FERMI-2 water-level transmitter, a very special design is required. To maximize the effectiveness of the attenuators for the 5 Hz frequency, three attenuators were recommended for installation. These attenuators will reduce the pressure waves at the transmitter by approximately 30-50%. To achieve maximum attenuation, it was estimated that the cylinder volume would have to be increased 100 times, which was not considered practical.

REFERENCES

1. C.D.I. Report No. 93-13, "Testing for Backfill Modification Transient Sensitivity," prepared for the BWROG (March 1994).

2. GENE-637-019-0893, Rev 0, "Analysis Guidelines for Backfill Modification of RPV Water Level Instrumentation," General Electric Co., prepared for the BWROG (August 1993).

Table 1

Summary of Selected Tests Results

Tests	Div	Description	Type of Event	Approximate Frequency At Transmitter	Approximate First Wave Magnitude	Approximate Second Wave Magnitude
10-6-2-2	II	CRD Pump Trip	Depress	5 Hz	+8"	-4"
10-6-2-3	II	CRD Pump Start	Press	5 Hz	-8"	+2 1/2"
10-6-2-6	II	HCU Accumulator Recharge	Press	5 Hz** .5 Hz	-8"*	+7"*
10-6-2-7	II	Scram	Depress	5 Hz	+14"	-7 1/2"
10-6-2-8	II	Scram Reset	Press	NA	-3"	+8"
10-6-2-9	II	Rod Pull	Press	1 Hz** 9 Hz	-5"	+4"

* These values were worst case magnitudes
** Two frequencies noted in those cases.

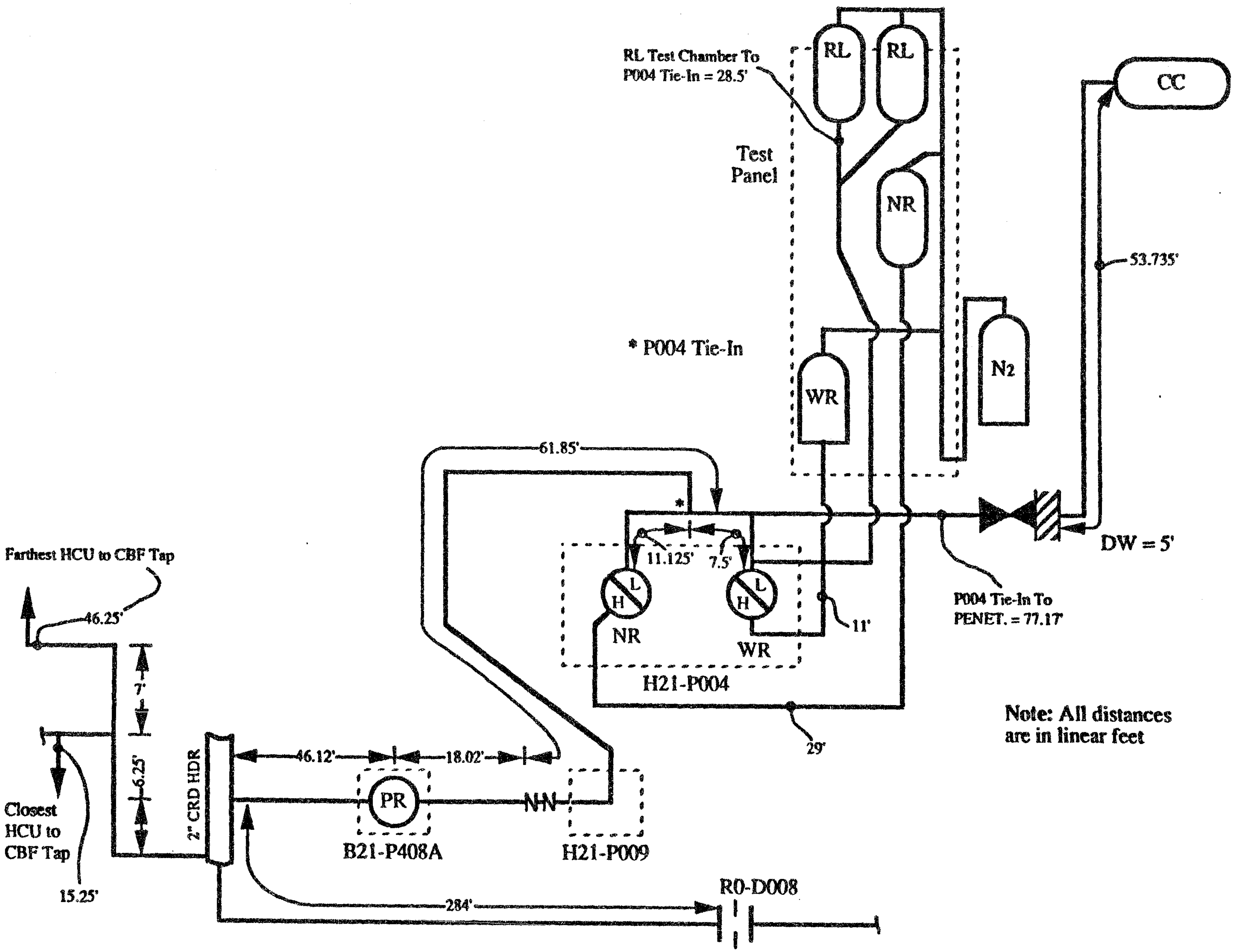

Figure 1 DIV 1 Backfill System Schematic With Distance Between Major Components

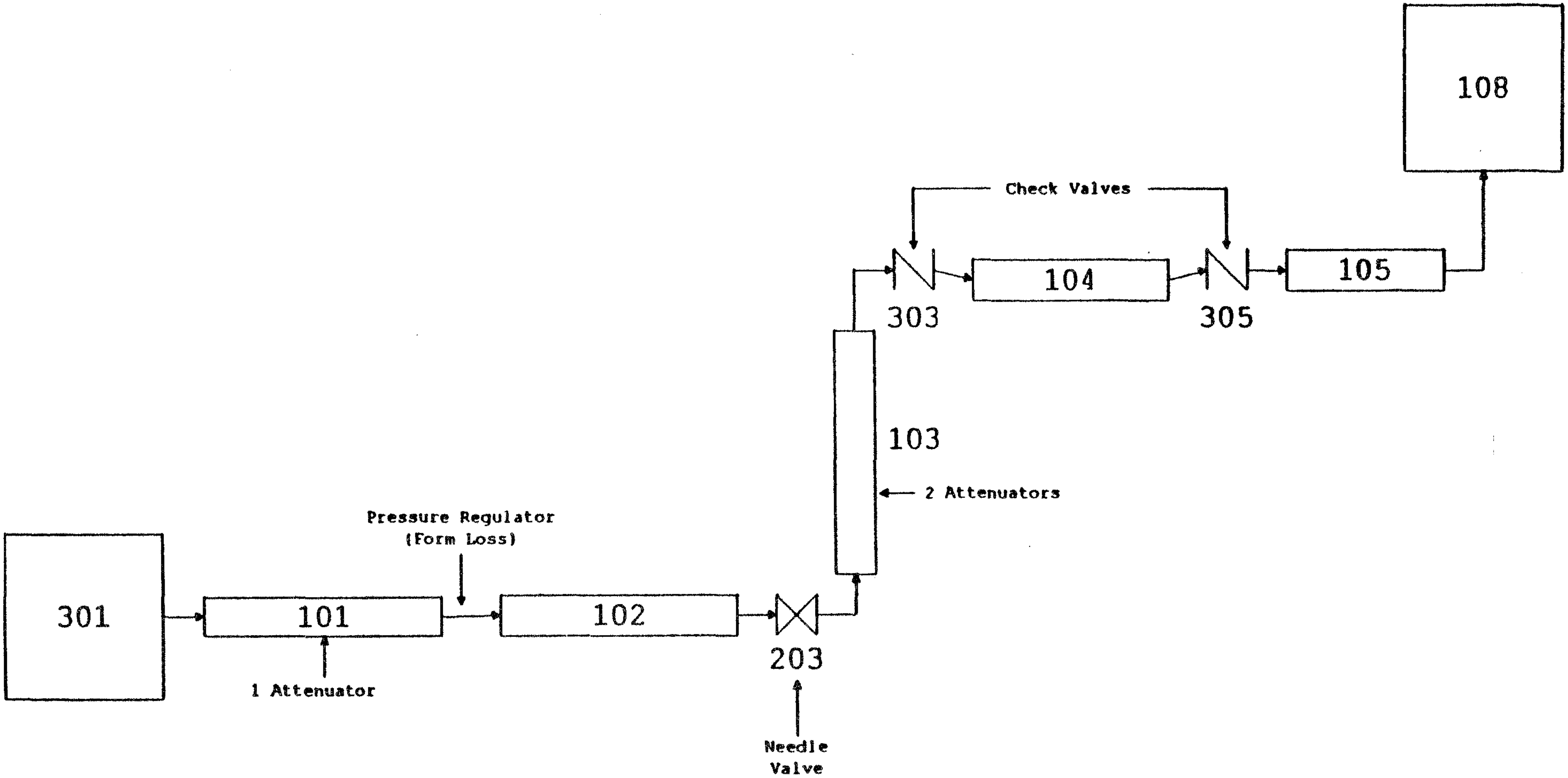

Figure 2
RELAP5/MOD3 Noding Diagram for Backfill Test Apparatus