OPERATION EXPERIENCES OF JOYO FUEL FAILURE DETECTION SYSTEM

Seiji Tamura and Takayoshi Hikichi

Experimental Fast Reactor Division

Hiroshi Rindo

Fast Breeder Reactor Development Project

January 1982

This document is prepared for the
third Japan/USSR seminar on methods
of testing of equipment, structural
materials and fuel of JOYO, BOR-60 and BR-10,
Tokyo, Japan, February 15-18, 1982.

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION

PNC TG033 82-01(3)
Jan, 1982

Operation Experiences of JOYO Fuel Failure Detection System

Seiji Tamura and Takayoshi Hikichi
Experimental Fast Reactor Division

Hiroshi Rindo
Fast Breeder Reactor Development Project

ABSTRACT

Monitoring of fuel failure in the experimental fast reactor JOYO is provided by two different methods, which are cover gas monitoring (FFDCGM) by means of a precpitator, and delayed neutron monitoring (FFD DNM) by means of neutron detectors.

The interpretation of signals which were obtained during the reactor operation for performance testings, was performed. The countrate of the CGM is approximately 120 cps at 75MW operation, whose sources are due to Ne^{23}, Ar^{41}, and Na^{24}. And the countrate of the DNM is approximately 2300 cps at 75MW operation which is mainly due to leakage neutron from the core. With those background of the systems, alarm level for monitoring was set at several times of each background level.

The reactor has been operated for 5 years, the burn-up of the fuel is 40,000 MWD/T at the most. No trace of any fuel failure has been observed. The fact is also proven by the results of cover gas and sodium sampling analysis.

In order to evaluate sensitivety of the FFD systems, a preliminary simulation study has been performed. According to the results, a signal level against one pin failure of 0.5 mm^2 hole may exceed the alarm level of the FFDCGM system.

1 Description of JOYO FFD system

The fuel failure monitoring in the experimental fast reactor JOYO is provided by two different methods, which are delayed neutron monitoring (DNM) system and cover gas monitoring (CGM) system.

For the DNM system, neutron counters, BF_3 and B-10, are installed at one of the primary hot leg pipings, so as to detect delayed neutrons emitted from fission product as Br^{87}, Br^{88}, $I^{137}$and I^{138}. DNM block layout is shown in Fig 1-1. As shown in Fig 1-2, the counters are surrounded by shielding materials, graphite blocks are to thermalize the delayed neutrons in order to increase sensitivety of the system, lead blocks are for gamma ray shielding, and polyethylene shielding is to reduce the background due to leakage neutron directly from the reactor core through th piping penetration.

In order to provide a broad monitoring range of the systems, two BF_3 counters, which signals are added each other to increase countrate, are used to cover the sensitive side of the range, and B-10 counter is used to monitor the other side of the range, in case of a big amount of fission products released.

The CGM system consists of piping systems, two vapor traps, a compressor and a precipitator as shown in Fig 1-3. The reactor cover gas is extracted from the reactor gas plenum and driven to the precipitator through one inch piping. The cover gas is sodium-trapped by two vapor traps and reaches the precipitation chamber. In this chamber, β decay daughters of fission products are precipitated on the negatively charged wire.

The precipitator is composed of a β-scintillation counter, wire, chamber, a wire drive motor and shielding, as illustrated in Fig 1-4. The wire is charged to 500 volts to collect β decay nuclides. The wire is driven from the chamber to the scintillation counter at an interval, and after being monitored, the wire is driven to the wire drum, which stores wire about one hundred times longer than one interval length. During the stay at the drum, the wire activity will decay.

Th_ precipitator has three nozzles, a sample gas inlet, a clean argon gas purge line and a gas outlet nozzle. Clean argon gas flows from scintillator side to the chamber through the wire guide hole to prevent the sample gas flowing to the detector and to reduce the background.

2 Interpretation of the signals

The background countrates of the system were obtained duting power ascension program, and are approximately 2300 cps for DNM and 120 cps for CGM at 75 MW operation.

The sources of the background were examined through day-by-day plant data. Fig 2-1 shows the decay curve of DNM at 50 MW scram testing. As the reactor was stopped, the countrate immedeately decreases as much as 94 % of the total, thereafter gradually decreases with a half life of 15 hr which is of Na^{24}. This 94 % of the total countrate is due to leakage neutron from the reactor core through the primary piping penetration at the reactor vessel. And 5 % of the total countrate coincides with the 15 hr-half-life and is supposed to be photoneutrons emitted at polyethylene by Na^{24}-gamma.

To study the source nuclides of the CGM background, wire drive was stopped during 50 MW operation. From the decay curve , shown in Fig 2-2, it was found that 60 % of the countrate is due to Ne^{23}. The nuclide Ne^{23} was identified by that the measured half life is close to that of Ne^{23}, and also by a gamma spectroscopy of the primary cover gas sampling system.

From the decay curve at scram test, shown in Fig 2-3, it is seen that the decay curve is separated into 2 hr half life component and longer half life component. The 2 hr half life component is supposed to be Ar^{41} and which dominates 20 % of the total background. The longer half life source of 15 hr is seen and contributes about 5 % of the total. This is supposed to be Na^{24} which was carried as vapor in the sampled gas. The Na^{24} saturation is seen when the reactor is operated at the rated power, as shown in Fig 2-4.

As mentioned above, the background of the both systems depend on the reactor power. The countrate vs reactor power is given in Fig 2-5. During the reactor operation alarm level of the system is set at 3 times and 6 times of the backgrounds for DNM and CGM respectively, and operation limit is provided at 5 times and 10 times of the backgrounds for DNM and CGM respectively. JOYO has been operated for 4 and half years, and no trace of fuel failure has been observed.

3 Simulation study of failure mode

In order to evaluate sensitivety of the system, a simulation study has been performed. Failure mode treated in the study is classified into slow leak failure and pin hole failure. The slow leak failure is defined as that a slight gas leak from the welding portion of the cladding and the leak is no longer observed when the reactor stopped. The pin hole failure is defined as a cladding failure with a hole of a few 10th mm^2 or more which is large enough to release whole FP gas immediately.

In the slow leak failure, the leaking gap is so small that the leak rate is to be constant, and the short-life halogenous FP gas decays before release from the cladding. The degree of the failure is represented by a pressure decay constant (T_d) which is defined as a time to let the pressure of the cladding decrease to half.

In the pin hole failure, the hole is large enough to release whole FP gas in the cladding. Thereafter, new-born FPs are released if the reactor is in operation. The release rate of FP gas depends on the size of the failure hole. In Fig's 3-1 and 3-2, conceptual behaviors of slow leak failure and pin hole failure are shown.

In the simulation modeling, the following mechanizms are taken into account.

1) FP inventory balance in fuel pin with failure,
2) FP escape from the failure pin as constant release model for slow leak failure, and as hole-size dependent release model for pin hole failure,
3) FP behavior model in the coolant as FP diffusion in the coolant, coolant flow and FP transition to the cover gas, and
4) Response of the FFD instruments.

Fig 3-3 shows CGM signal response to slow leak failure, as a parameter of pressure decay constant (T_d). As seen in the Fig 3-3, the countrate exceeds the alarm level (720 cps) of the CGM system. In the DNM system, however, detection of slow leak failure is not possible, since halogenous FP gas is short-life nuclide, and decays before detected.

For the pin hole failure, fuel failure with 0.5 mm^2 hole is detectable by both CGM and DNM. Signal responses of the systems are shown in Fig 3-4 and Fig 3-5.

4 Conclusion

The experimental fast reactor JOYO has been operated for more than 10,000 hr, and the maximum burn-up fuel reached 40,000 MWD/T. Up to now, no fuel failure, nor tramp fuel has been observed.

In order to evaluate sensitivety of the FFD system, study is beeing proceeded analytically and empirically. According to the preliminary simulation study, a signal level against one pin failure of 0.5 mm^2 hole may exceed the alarm level of the CGM system.

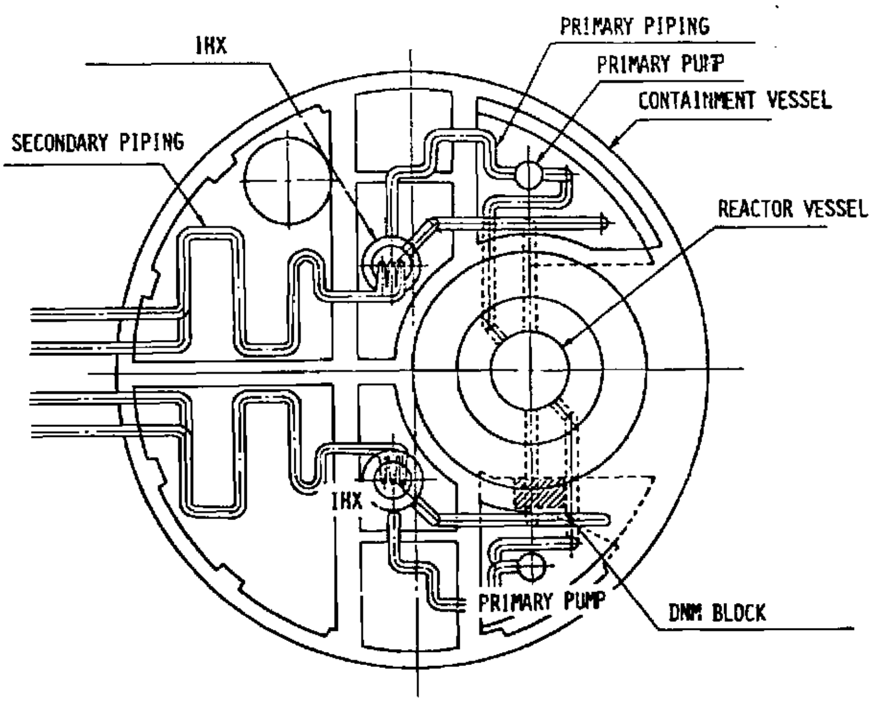

Fig 1-1 DNM BLOCK LAYOUT

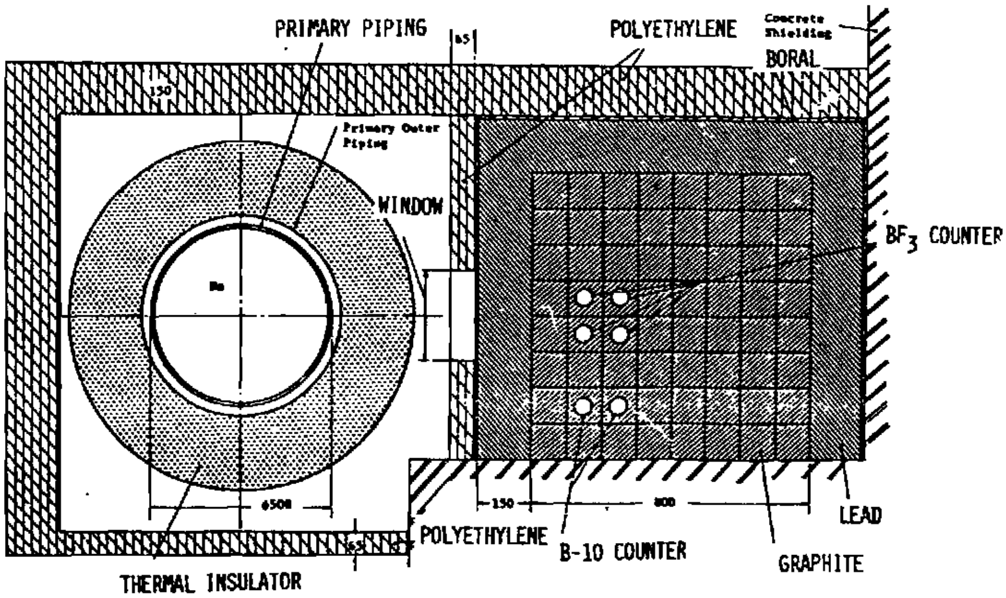

Fig 1-2 DELAYED NEUTRON MONITORING BLOCK

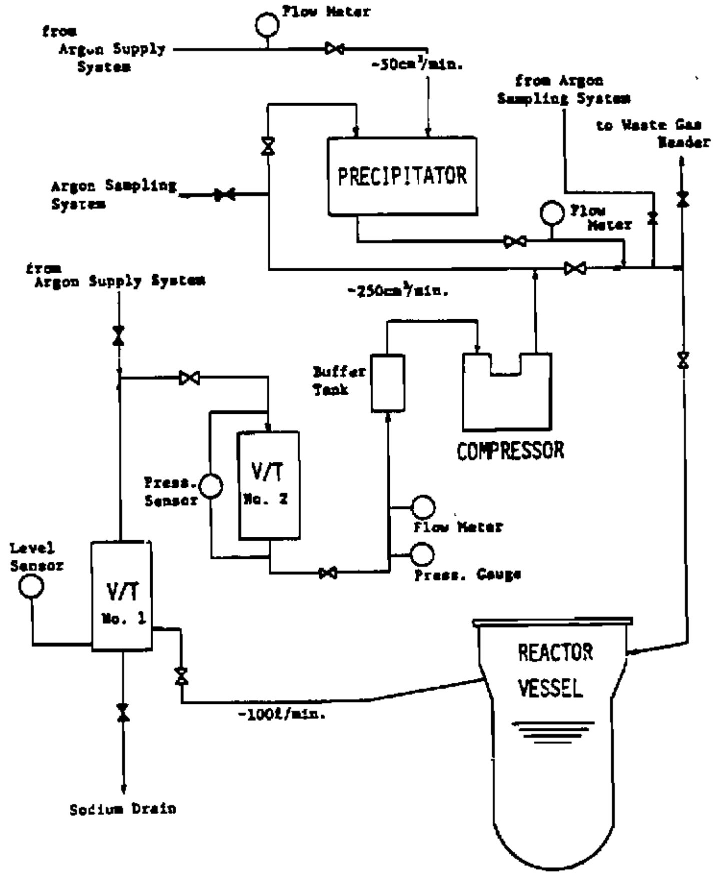

Fig 1-3 BLOCK DIAGRAM OF FFDCGM SYSTEM

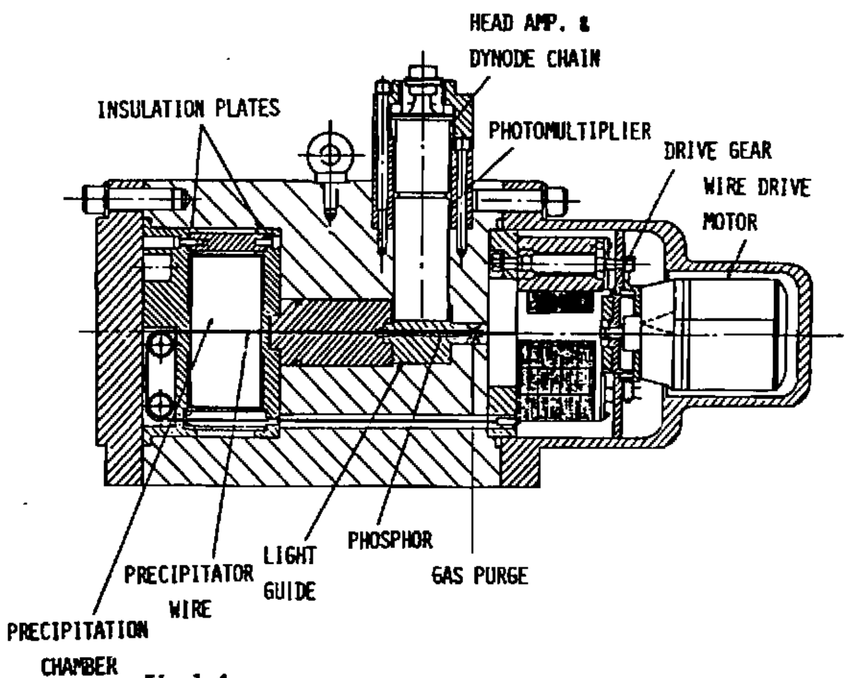

Fig 1-4 CROSS SECTION OF PRECIPITATOR

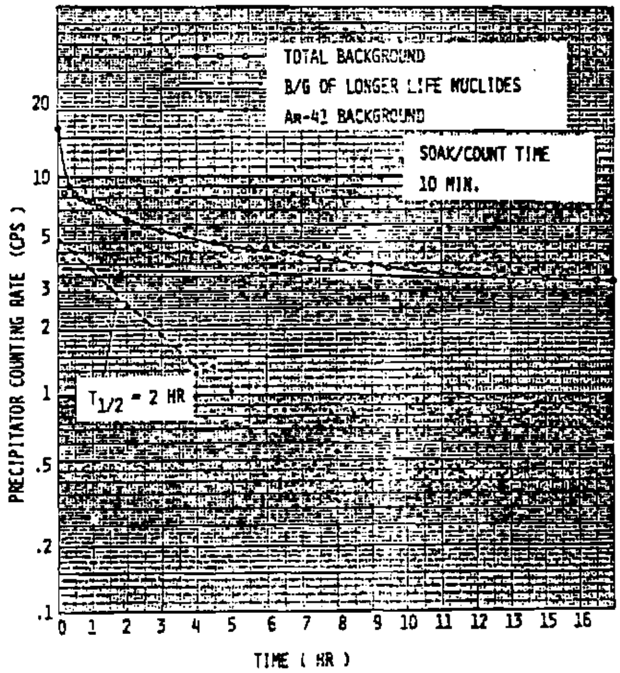

Fig 2-3 DECAY CURVE OF BACKGROUND AFTER SCRAM AT 25MW OPERATION

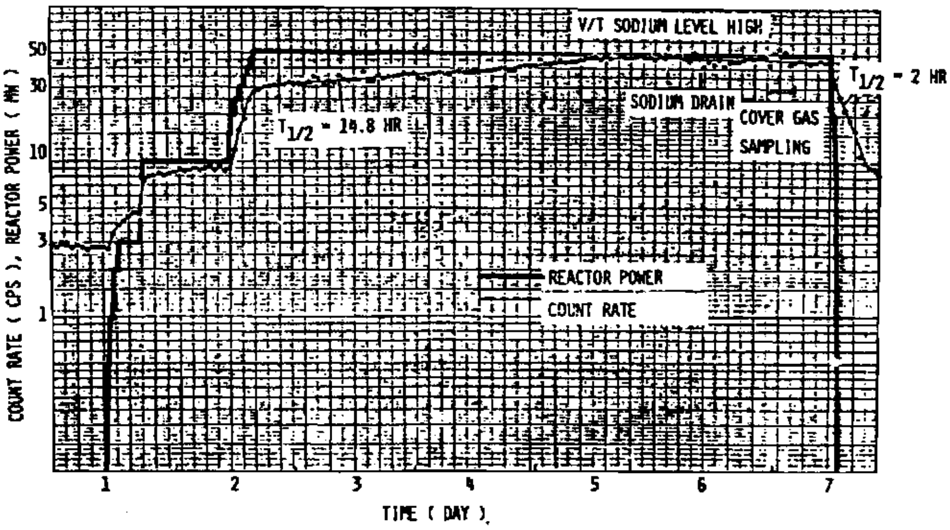

Fig 2-4 PRECIPITATOR COUNT RATE DURING 50MW DEMONSTRATION OPERATION

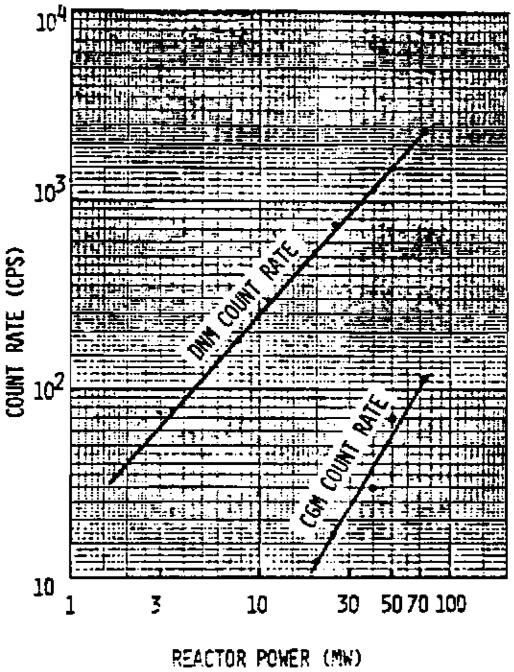

Fig 2-5 DNM AND CGM COUNT RATES VS REACTOR POWER

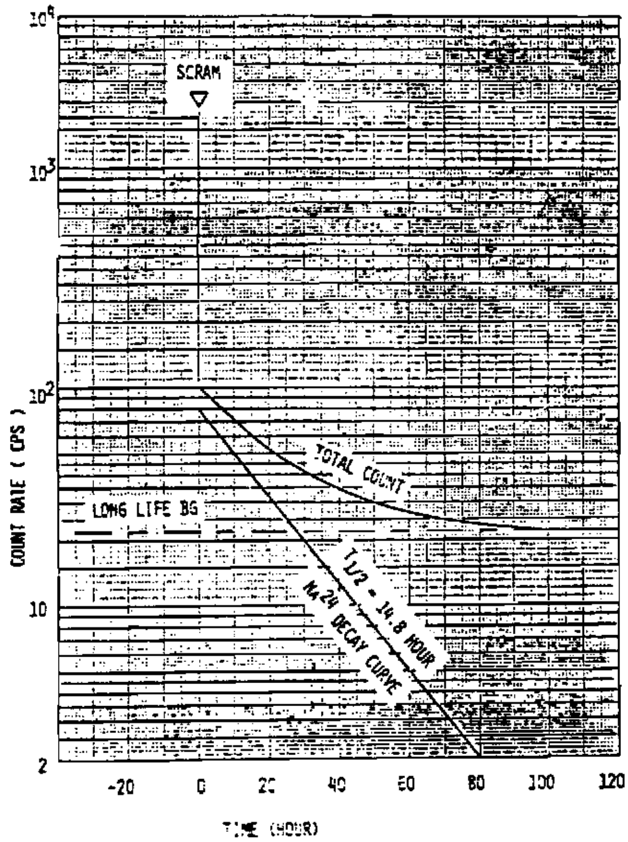

Fig 2-1 DECAY CURVE OF DNM SIGNAL AFTER SCRAM AT 50MW OPERATION

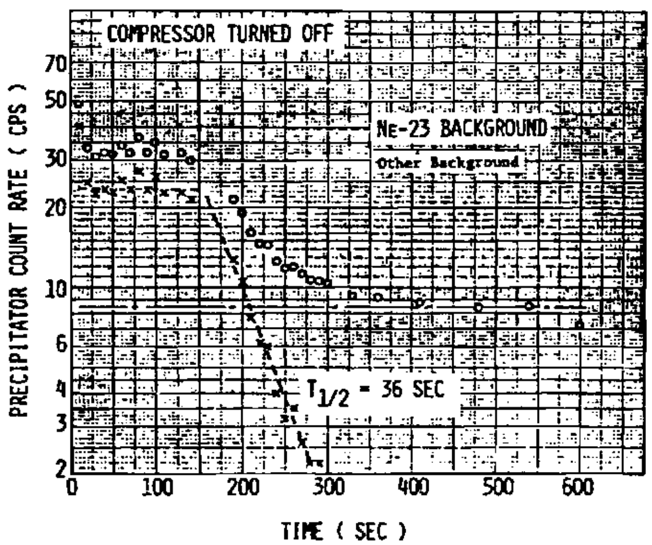

Fig 2-2 DECAY CURVE OF PRECIPITATOR WHEN GAS FLOW WAS STOPPED AT 50 MW OPERATION

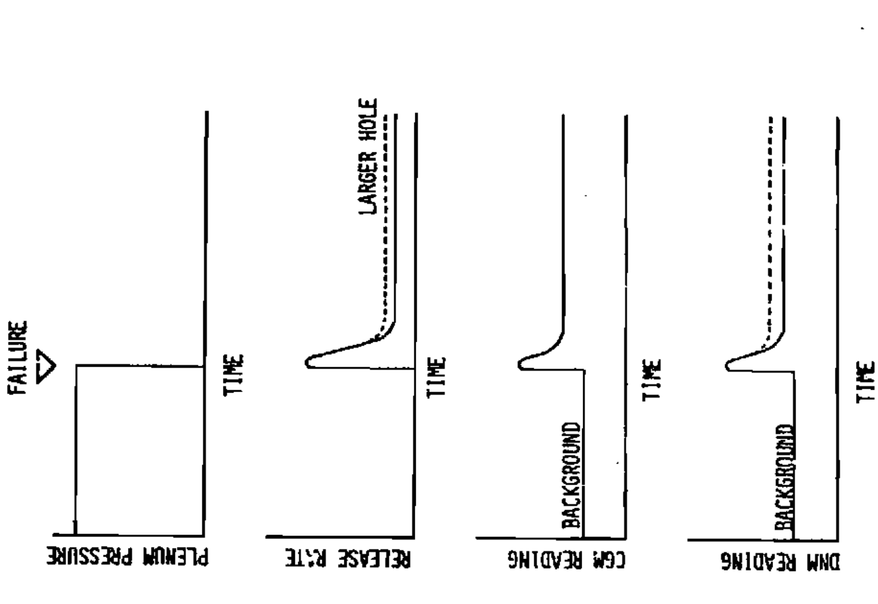

Fig 3-2 FP RELEASE AND, CGM AND DNM RESPONSE TO PIN HOLE FAILURE

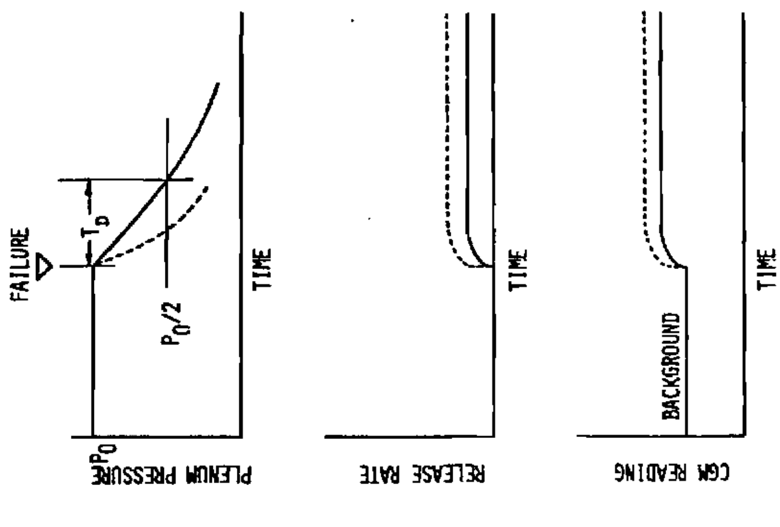

Fig 3-1 FP RELEASE AND CGM RESPONSE TO SLOW LEAK FAILURE

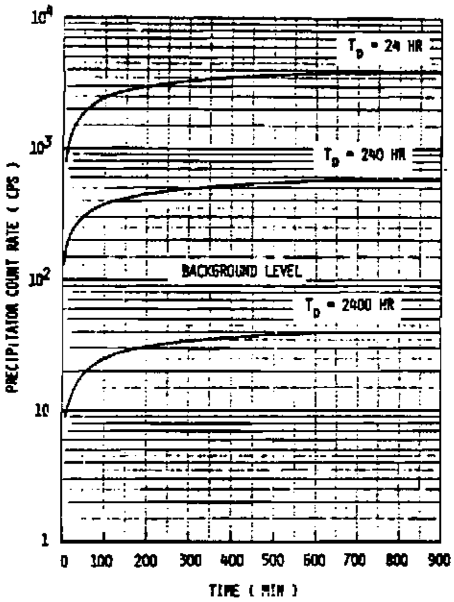

Fig 3-3 SIMULATION STUDY, CGM RESPONSE TO SLOW LEAK FAILURE

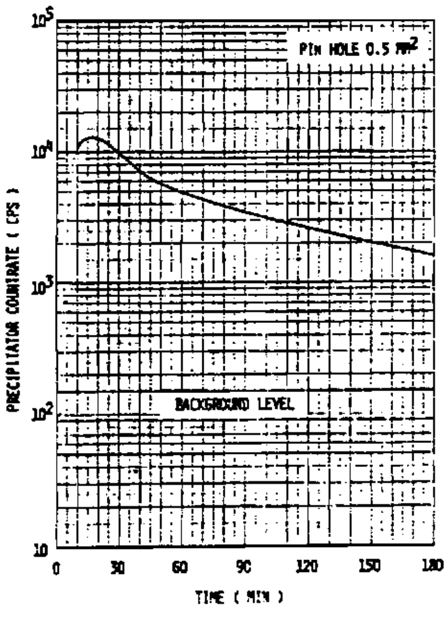

Fig 3-4 SIMULATION STUDY, CGM RESPONSE TO PIN HOLE FAILURE

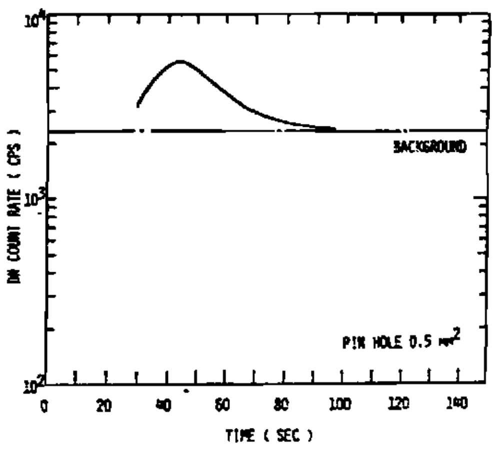

Fig 3-5 SIMULATION STUDY, DNM RESPONSE TO PIN HOLE FAILURE