4.10 NUCLEAR SYSTEM LEAKAGE RATE LIMITS

4.10.1 Safety Objective

Nuclear system leakage rate limits are established so that appropriate action can be taken before the integrity of the nuclear system process barrier is unduly compromised.

4.10.2 Safety Design Basis

1. The nuclear system leakage rate limit shall be set so that corrective action can be taken:

    a. Before the nuclear system process barrier is threatened with significant compromise,

    b. Before the rate of leakage exceeds the coolant makeup capability, and

    c. Before the total leakage rate within the drywell exceeds the capability for leakage removal from the drywell.

2. Means shall be provided for the detection of leakage rates so that corrective action can be taken before the integrity of the nuclear system process barrier is unduly compromised.

4.10.3 Description

This subsection describes the leakage detection systems which are provided to detect abnormal leakage from the nuclear system process barrier inside the primary containment. Also discussed in this subsection are nuclear system leakage rate limits and how they are established.

The systems that detect gross leakage resulting from a pipe rupture outside the primary containment (such as in the main steam lines, HPCI steam line, RCIC steam line, and reactor water cleanup lines) and initiate automatic isolation are considered as part of the Primary Containment and Reactor Vessel Isolation Control System; and they are discussed in Section 7.3, "Primary Containment Isolation System."

Collection and processing of leakage outside the primary containment in the Reactor Building and in all other buildings are discussed in Section 10.16, "Equipment and Floor Drainage Systems," and Section 9.2, "Liquid Radwaste System."

Figures 4.10-1 and 9.2-3j are diagrams of the drywell leak detection system (except for the drywell leak detection radiation monitoring system) and drywell sumps, respectively. As shown in the figures, there are two drywell sumps. One

sump (drywell equipment drain sump) receives drainage from the pump seal leak-off, reactor vessel head flange vent drain, and other equipment drains. The second sump (floor drain collector sump) receives control rod drive, valve stem, and flange leakages, floor drains, closed cooling water system drains and drywell cooling unit condensation. Collection of leakage in excess of normal background amounts is indicative of a process system leak. For anticipated leakage rates of equipment and specific piping paths, see Section 9.2, "Liquid Radwaste System."

Leaks within the primary containment are detected by: (a) increased pressure and temperature in the primary containment, (b) monitoring the flow in the equipment drain sump and floor drain sump, (c) monitoring the cooling water temperature to and from the drywell coolers, and (d) monitoring the drywell for airborne activity (7.14).

The drywell cooling system recirculates the drywell atmosphere through heat exchangers to maintain the drywell at its design operating temperature. With the drywell atmospheric coolers operating inside a sealed drywell, an abnormal temperature rise inside the drywell would indicate a coolant and/or steam leak.

The drywell leak detection radiation monitoring system consists of four sample points, two near the top of the spherical portion of the drywell, 180° apart, and two near the recirculation pumps, 180° apart. The two top samples are manifolded together and routed through one line in an instrument drywell penetration. The two lower samples are manifolded and routed through another line in the same instrument drywell penetration. Two automatic isolation valves are provided in series in each line outside the drywell. The two lines are manifolded together and routed to a radiation monitor. The sample return from the radiation monitor is provided with two automatic isolation valves and routed through another line in an instrument drywell penetration. The inlet and return automatic isolation valves close on primary containment isolation and are provided with override switches in the main control room.

Detection, identification, and measurement of leakage in the drywell have been separated into identified and unidentified leakage. Limits have been established for unidentified and total leakage inside the drywell. Total leakage is defined as the sum of the identified and unidentified leakage.

4.10.3.1 <u>Identified Leakage Rate</u>

The identified leakage rate is the sum of all component leakage rates that input into the drywell equipment drain sump.

The pump packing glands and other seals in systems that are part of the nuclear system process barrier, and from which normal design leakage is expected, are provided with drains or auxiliary sealing systems. The valves in Units 2 and 3 and

pumps in the Reactor Recirculation System inside the drywell are equipped with double seals. The pump suction and discharge valves of Reactor Recirculation System in Unit 1 are equipped with live load packing. Leakage from the primary recirculation pump seals is piped to the equipment drain sump as described in Section 4.3, "Reactor Recirculation System." Leakage from the main steam relief valves is identified by temperature sensors which transmit to the Main Control Room. Any temperature increase detected by these sensors above the drywell ambient temperature indicates valve leakage. Unambiguous Main Control Room indication and alarm of valve position is provided by use of an acoustic monitoring system on the main steam relief valve tailpipes. Leakage from the reactor vessel head flange gasket is piped to a collection chamber and then to the equipment drain sump. A more detailed discussion is presented in Section 7.8, "Reactor Vessel Instrumentation."

Thus, the leakage rates from pumps, valve seals, and the reactor vessel head seal are measurable during operation of the plant. These leakage rates, plus any other leakage rates that input into the drywell equipment drain sump, are defined as identified leakage rates.

4.10.3.2 Unidentified Leakage Rate

The unidentified leakage rate is the rate at which leakage enters the drywell floor drain sumps. A threat of significant compromise to the nuclear system process barrier exists if the barrier contains a crack that is large enough to propagate rapidly. The unidentified leakage rate is limited because of the possibility that most of the unidentified leakage rate might be emitted from a single crack in the nuclear system process barrier.

A leakage rate of 150 gpm has been conservatively calculated to be the minimum liquid leakage from a crack large enough to propagate rapidly. An allowance for reasonable leakage that does not compromise barrier integrity, and is not identifiable, is made for normal plant operation.

The unidentified leakage rate limit is established at 5 gpm, which is far enough below the 150 gpm leakage rate to allow time for corrective action to be taken before the process barrier is significantly compromised.

Both the GE (GEAP-5260, Failure Behavior in ASTM A106B Pipes Containing Axial Through-wall Flows, by M. B. Reynolds, April 1968) and the BMI (Recent Work on Flow Behavior in Pressure Vessels, by A. R. Duffy, R. J. Eiber, and W. A. Maxey, April 1969); also, Quarterly Progress Reports, "Investigation of the Initiation and Extent of Ductile Pipe Rupture," by Eiber, et al, for the period May 1966 through 1969) test results indicate that theoretical fracture mechanics formulas do not predict critical crack length, but that satisfactory empirical expressions may be developed to

fit test results. A simple equation which fits the data in the range of normal design stresses (for carbon steel pipe) is as follows.

(1) Crack Length.

$$lc = \frac{15{,}000 \quad D}{\sigma_h}$$

(see data correlation on Figure 4.10-3),

where:

lc = critical crack length (inches)
D = mean pipe diameter (inches)
σ_h = nominal hoop stress (psi).

(2) Crack Opening Displacement. The theory of elasticity predicts a crack opening displacement of

$$\omega = \frac{2 \quad 1\sigma}{E}$$

where:

l = crack length
σ = applied nominal stress
E = Young's Modulus.

Measurements of crack opening displacement made by BMI show that local yielding greatly increases the crack opening displacement as the applied stress approaches the failure stress σf. A suitable correction factor for plasticity effects is

$$c = \sec\left(\frac{\pi}{2} \bullet \frac{\sigma}{\sigma_f}\right)$$

The crack opening area is given by

$$A = C \frac{\pi}{4} \omega 1 = \frac{\pi 1^2 \sigma}{2E} \sec \left(\frac{\pi}{2} \times \frac{\sigma}{\sigma_f} \right)$$

For a given crack length l, sf = 15,000 D/l.

(3) Leakage Flow Rate. The maximum flow rate for blowdown of saturated water at 1000 psi is 55 lb/sec-in.^{2} and for saturated steam the rate is 14.6 lb/sec-in.^{2} (APED-4827, Maximum Two-Phase Vessel Blowdown from Pipes, by F. J. Moody, April 1965). Friction in the flow passage reduces this rate, but for cracks leaking at 15 gpm (2.08 lb/sec), the effect of friction is small. The required leak size for 15 gpm flow is

A = 0.038 in.^{2} (saturated water)

A = 0.143 in.^{2} (saturated steam).

From this mathematical model, the critical crack length and the 15 gpm crack length have been calculated for representative BWR pipe sizes (Schedule 80) and pressure (1050 psi). The lengths of through-wall cracks that would leak at the rate of 15 gpm as a function of nominal pipe size are as follows.

Nominal Pipe Size (Sch 80)	Critical Crack Length (inches)	15 gpm Crack Steam Line	Length(inches) Water Line
4	9.6	8.4	6.7
12	19.6	12.1	7.5
24	34.8	14.0	7.8

It is important to recognize that the failure of ductile piping with a long, through-wall crack is characterized by large crack opening displacements which precede unstable rupture. Judging from observed crack behavior in the GE and BMI experimental programs, involving both circumferential and axial cracks, it is estimated that leak rates of hundreds of gpm will precede crack instability. Measured crack-opening displacements for the BMI experiments were in the range of 0.1 to 0.2 inches at the time of incipient rupture, corresponding to leaks of the order of one square inch in size for plain carbon steel piping. For austenitic stainless steel piping, even larger leaks are expected to precede crack instability, although there is insufficient data to permit quantitative prediction.

4.10.3.3 Total Leakage Rate

Total leakage rate consists of all leakage, identified and unidentified, which flows to the drywell floor drain and equipment drain sumps.

The criterion for establishing the total leakage rate limit is based on the makeup capability of the Control Rod Drive (CRD) and the RCIC systems which are independent of the feedwater system, normal AC power for two of the five CRD pumps, and the Core Standby Cooling Systems. The CRD system supplies makeup into the reactor vessel; the RCIC system can supply 600 gpm through the feedwater sparger to the reactor vessel. The total leakage rate limit is established at 30 gpm, which is substantially below the minimum normal inflow of the CRD System.

The total leakage rate is also set low enough to prevent overflow of the drywell sumps. The equipment drain sump (capacity 1,000 gallons) and the floor drain sump (capacity 1,000 gallons), which collect all leakage, are each drained, when required, by operation of a single pump throttled to operate at approximately 50 gpm. Dual sump pumps are available in each sump for redundancy. The total leakage rate limit is set below the removal capacity of a single pump in each sump because of the possibility that most of the total leakage could flow into one sump.

Each sump has an alarm system and automatic pump-starting sequence as follows. At the first high-water-level setting, the preselected pump is automatically started. If the water level continues to rise, a higher water-level setting starts the standby pump and actuates an alarm. The pumps are alternately selected for operation by an automatic pump-selector switch. The alarm indicates that leakage into that sump is equal to, or is exceeding, the capacity of one pump or that the preferred pump failed to start.

PCIS Isolation Valves: 1/2/3-FCV-77-2B, Drywell Floor Drain Sump Outboard Isolation Valves, and 1/2/3-FCV-77-15B, Drywell Equipment Drain Sump Outboard Isolation Valve are maintained in the closed position. With these valves now closed, the Sump Pumps auto start will be inhibited. There will not be an automatic high sump level start of the DW Floor Drain Sump pumps or the Unit 3 DW Equipment Drain Sump Pumps. Operator action will be required on high level and temperature to initiate start of pumps.

The flow integrators are combined with the flow recorder and presented as separate output channels on the flow recorder. Total leakage rate is periodically calculated from these flow integrators. A flow recorder continually plots time-versus-discharge flow rate from each sump; an increase in leakage rate is detectable by an increase in sump-discharge flow time and an increased frequency in discharge flow cycles. Increases in total leakage rate are also detectable from records kept of flow integrator readings.

A pump running timer records the actual amount of time each sump pump runs. By utilizing the known capacity of the sump pump and a pump-run-time, real time comparison on average leakage rate is established. If this average leakage rate exceeds a pre-established limit, an alarm sounds in the control room. The drywell equipment drain sump timer does not perform this function when there is a high water level coupled with persistent high temperature. The pump stays in recirculation mode when not discharging and the alarm does not indicate excessive leakage rate.

4.10.4 Safety Evaluation

The unidentified leakage rate limit is based, with an adequate margin for contingencies, on the crack size large enough to propagate rapidly. The established limit is sufficiently low so that, even if the entire unidentified leakage rate were coming from a single crack in the nuclear system process barrier, corrective action could be taken before the integrity of the barrier is threatened with significant compromise.

The limit on total leakage rate is established so that in the absence of normal AC power and feedwater, and without using the Core Standby Cooling Systems, the leakage loss from the nuclear system could be replaced. The CRD system furnishes normal makeup and the RCIC system can furnish 600 gpm to the reactor vessel, both of which are independent of feedwater. The RCIC and two of five CRD pumps for the plant are independent of normal AC power. The limit on total leakage also allows a reasonable margin below the discharge capability of either the floor drain or equipment drain sump pumps. Thus, the established, total-leakage rate limit allows sufficient time for corrective action to be taken before either the nuclear system coolant makeup or the drywell sump removal capabilities are exceeded. Safety design basis 1 is therefore satisfied.

A discussion of the leakage detection instrumentation is provided in the description. This information shows that means are provided for the detection of leakage so that corrective action can be taken before the integrity of the nuclear system process barrier is unduly compromised. This provision satisfies safety design basis 2.

4.10.5 Inspection and Testing

The pumps and controls are periodically inspected and tested to verify proper operation and instrument operability. Readings from the drywell sump and radiation monitoring systems are checked and recorded as appropriate based on requirements of Technical Specifications, Sections 3.4.4 and 3.4.5.