14.3 REACTOR COOLANT SYSTEM PIPE RUPTURE (LOSS OF COOLANT ACCIDENT)

14.3.4 Containment Integrity Analysis

14.3.4.4 Mass and Energy Release Analysis for Postulated Secondary System Pipe Ruptures Inside Containment

A series of steamline breaks were analyzed to determine the most severe break condition for the containment temperature and pressure response. The assumptions on the initial conditions are taken to maximize the mass and energy released. The range of possible operating conditions for the Donald C. Cook Nuclear Plants are presented in Table 14.1-1 for Unit 1 and Table 14.1.0-1 for Unit 2. The subsections that follow discuss; the short-term mass and energy releases, which addresses steamline break effects in the steam generator enclosure and the fan accumulator room, and a feedwater line break in the steam generator enclosure, followed by the long-term mass and energy releases.

14.3.4.4.1 Short Term Mass and Energy Releases

The short term mass and energy releases are broken down into steamline break locations in the fan accumulator room and steam line and feedwater line breaks in the steam generator doghouses. The details of each of these break locations are discussed below. The limiting plant condition in terms of both steam generator mass inventory and initial secondary system pressure are obtained when the plant is at hot shutdown. Since the no-load conditions are identical for both Unit 1 and Unit 2, one group of short term mass and energy release analyses will be applicable for both units.

Initial blowdown from the steam generator will be dry steam as a result of the approximately 5000 lbm. of steam in the upper head. This accentuates the initial peak compartment pressure. For the doghouse break, the flow rate was based on the Moody correlation for an initial reservoir pressure of 1106 psia, and included the steam generator exit nozzle loss. This was the value originally used for Unit 2 at the time of initial licensing. This is conservative to the licensing basis no-load pressure of 1020 psia. Depressurization of the steam generator causes an initial decrease in steam flow.

The following assumptions were made for calculating steam generator blowdown with entrainment. Note that these assumptions are in the conservative direction for maximum water entrainment.

1. No credit was taken for the separation capability of the steam generator internals (swirl vanes and dryers).
2. Flow between regions of the steam generator was assumed as homogeneous with no slip or separation. Regions of the steam generator are the downcomer, bundle, swirl vane cylinders, and dryers.
3. Flow resistance between the steam generator regions was considered.
4. No credit was taken for flow resistance in the piping between the steam generator and the break.
5. Break flow was determined by the Moody (Reference 25 of Section 14.3.4.7) correlation with the discharge coefficient conservatively assumed as unity.

The mass and energy releases were also calculated for a postulated break in the main feedwater piping. For the feedwater line break event, the no-load steam generator pressure is 1020 psia and the full-power feedwater temperature is 449°F. Both the steam generator and the main feedwater system are assumed at saturation conditions for purposes of determining the liquid enthalpy values. The initial mass in the steam generator is 180,400 lb_m.

14.3.4.4.1.1 Steam Generator Doghouse

The mass and energy release to the steam generator doghouse from a steamline break and a feedwater line break has been analyzed. One case considers a steam line break between the steam generator shell and the steam line flow restrictor (break at the steam generator nozzle). The postulated break area is 4.60 ft^2 in the forward flow direction (normal direction of the steam flow) based on the inside diameter of the pipe. The break area defined in the reverse flow direction (opposite direction of the normal steam flow) is 4.909 ft^2 based on the inside diameter of the pipe. After the initial blowdown of the steam pipe, the reverse direction flowrate is limited by the area (1.4 ft^2) defined by the inline flow restrictor (venturi) on the faulted steam line. The inline flow restrictor is located in the turbine bypass header in the turbine building. The second case models a feedwater line break at the nozzle to the steam generator, downstream of the feedwater line check valve. The feedwater line break area is 1.117 ft^2, which corresponds to a nominal pipe diameter of 16" with an inside diameter of 14.314".

The calculated mass and energy release rates into the steam generator doghouse, for both break locations, are presented as Table 14.3.4-15.

14.3.4.4.1.2 Fan Accumulator Room

Blowdown of the steam piping was calculated with the SATAN-4 computer code. The SATAN-4 code does not consider momentum flux. Neglect of this effect is conservative for high velocity steam blowdown since it overpredicts the steam pressure near the break. Since steam pressure and steam density are overpredicted, frictional losses are underpredicted.

Piping blowdown consists of steam at 1192 Btu/lbm (saturation enthalpy at 1020 psia).

Steam piping blowdown consists of reverse flow (steam flow coming out the turbine end of the break), and -- for the break in the fan room -- the initial steam blowdown from the steam generator end until choking conditions are reached in the flow restrictor.

The SATAN model consists of 69 elements simulating the four steam generators and steam lines and the steam dump header. For the fan room analysis, flow restrictors with a throat area of 1.4 ft^2 were assumed in the steam line cross ties near the turbine.

Reverse flow was assumed to be terminated after 10 seconds as a result of steam line isolation. No credit was taken for partial isolation valve closure prior to 10 seconds.

The calculated mass and energy release rates for the fan accumulator room steam line break analyses are presented in Table 14.3.4-17.

14.3.4.4.2 Long Term Mass and Energy Release Data

The mass / energy release calculations were conservatively performed assuming a bounding uprated power level. The upper bound parameters used for the analysis are presented in Table 14.3.4-47.

14.3.4.4.2.1 Pipe Break Blowdowns Spectra and Assumptions

The following assumptions were used in the analysis:

a. Double ended pipe breaks were assumed to occur at the nozzle of one steam generator and also downstream of the flow restrictor. Split pipe ruptures were assumed to occur at the nozzle of one steam generator.

b. The blowdown was assumed to be dry saturated steam.

c. The steamline break protection system design was assumed to actuate on low steam line pressure.

d. Steamline isolation was assumed complete 11.0 seconds after the setpoint is reached for either low steam pressure or hi-hi containment pressure. The isolation time allows 8 seconds for valve closure plus 3 seconds for electronic delays and signal processing. The total delay time for steamline isolation of 11 seconds was assumed to support the relaxation of the main steam isolation valve (MSIV) closure time.

e. 4.6 and 1.4 square foot double ended pipe breaks were evaluated at 102, 70, 30 and zero percent power levels of 3588 MWt core thermal power.

f. Four (4) combinations of steamline ruptures were evaluated assuming split pipe ruptures: 0.86 square foot equivalent diameter at 102 percent power, 0.908 square foot equivalent diameter at 70 percent power, 0.942 square foot equivalent diameter at 30 percent power, and 0.40 square foot equivalent diameter at hot shutdown.

g. Failure of a main steam isolation valve, failure of feedwater isolation or main feed pump trip, and failure of auxiliary feedwater runout control were considered. Two cases for each break size and power level scenario were evaluated with one case modeling the MSIV failure and the other case modeling the AFW runout control failure. Each case assumed conservative main feedwater addition to bound the feedwater isolation or main feed pump trip failure.

h. The end-of-life shutdown margin was assumed to be 1.3% $\Delta k/k$ at no load, equilibrium xenon conditions, and the most reactive RCCA stuck in its fully withdrawn position.

i. A moderator density coefficient of 0.54 Δk/gm/cc was assumed.

j. Minimum capability for injection of boric acid (2400 ppm) solution was assumed corresponding to the most restrictive single failure in the safety injection system. The emergency core cooling system (ECCS) consists of the following systems:

   1. the passive accumulators,
   2. the low head safety injection (residual heat removal) system,
   3. the intermediate head safety injection system, and
   4. the high head safety injection (charging) system.

Only the high head safety injection (charging) system and the passive accumulators were modeled for the steam line break accident analysis.

The modeling of the safety injection system in LOFTRAN is described in Reference 26. Figure 3.3-52 of WCAP-11902 presents the safety injection flow rates as a function of RCS pressure assumed in the analysis. The flow corresponded to one charging pump delivering its full flow to the cold legs. The safety injection flows assumed in this analysis take into account the degradation of the ECCS charging pump performance. No credit was taken for the low concentration borated water that must be swept from the lines downstream of the boron injection tank isolation valves prior to the delivery of boric acid to the reactor coolant loops. For this analysis, a boron concentration of 0 ppm for the boron injection tank was assumed.

After the generation of the safety injection signal (appropriate delays for instrumentation, logic and signal transport included), the appropriate valves begin to operate and the safety injection charging pump starts. In 27 seconds, the valves were assumed to be in their final position and the pump was assumed to be at full speed and to draw suction from the RWST. The volume containing the low concentration borated water is swept into the core before the 2400 ppm borated water reaches the core. This delay, described above, was inherently included in the modeling.

k. For the at-power cases, reactor trip was available by safety injection signal, overpower protection signal (high neutron flux reactor trip or OPΔT reactor trip), and low pressurizer pressure reactor trip signal.

l. Offsite power was assumed available. Continued operation of the reactor coolant pumps maximizes the energy transferred from the reactor coolant system to the steam generators.

m. No steam generator tube plugging was assumed to maximize the heat transfer characteristics.

14.3.4.4.2.2 Break Flow Calculations

a. Steam Generator Blowdown

The LOFTRAN computer code (Reference 26) was used to calculate the break flows and enthalpies of the release through the steam line break. Blowdown mass/energy releases determined using LOFTRAN include the effects of core power generation, main and auxiliary feedwater additions, engineered safeguards systems, reactor coolant thick metal heat storage, and reverse steam generator heat transfer.

b. Steam Plant Piping Blowdown

The calculated mass and energy releases include the contribution from the secondary steam piping. For all ruptures, the steam piping volume blowdown begins at the time of the break and continues until the entire piping inventory is released. The flow rate is determined using the Moody correlation and the pipe cross sectional area.

14.3.4.4.2.3 Single Failure Effects

a. Failure of a main steam isolation valve (MSIV) increases the volume of steam piping that is not isolated from the break. When all valves operate, the piping volume capable of blowing down is located between the steam generator and the first isolation valve. If this valve fails, the volume between the break and the isolation valves in the other steam lines, including safety and relief valve headers and other connecting lines, will feed the break. For all cases, the steam line volumes associated with Unit 1 were conservatively assumed since the volume available for blowdown is greater than Unit 2.

b. Failure of a diesel generator would result in the loss of one containment safeguards train, resulting in minimum heat removal capability.

c. Failure of the main feedwater regulating valve (MFRV) to close results in additional inventory in the feedwater line that would not be isolated from the steam generator. The mass in this volume can flash to steam and exit through the break. All steamline break cases conservatively assumed failure of the MFRV to close, which resulted in the additional inventory available for release through the steamline break as well as a longer duration for the higher than normal main feedwater flows before the backup main feedwater motor-operated isolation valve (MFIV) closes.

d. Failure of the auxiliary feedwater runout control equipment could result in higher auxiliary feedwater flows entering the steam generator prior to realignment of the auxiliary feedwater system. For cases where the runout control operates properly, a constant auxiliary feedwater flow of 775 gpm to the faulted steam generator was assumed. This value was increased to 1381 gpm to simulate a failure of the runout control.

The long-term steamline break analysis calculated mass and energy rates for both the double-ended rupture and the split-breaks are presented in Tables 14.3.4-7 and 14.3.4-8, respectively.