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

14.3.4 Containment Integrity Analysis

14.3.4.3 Mass And Energy Release Analysis For Postulated Loss-Of-Coolant Accidents

This analysis presents the mass and energy releases to the containment subsequent to a hypothetical loss-of-coolant (LOCA).

The LOCA transient is typically divided into four phases:

1. Blowdown - which includes the period from accident initiation (when the reactor is at steady state operation) to the time that the RCS reaches initial equilibration with containment.
2. Refill - the period of time when the lower plenum is being filled by accumulator and safety injection water. At the end of blowdown, a large amount of water remains in the cold legs, downcomer, and lower plenum. To conservatively consider the refill period for the purpose of containment mass and energy releases, this water is instantaneously transferred to the lower plenum along with sufficient accumulator water to completely fill the lower plenum. This allows an uninterrupted release of mass and energy to containment. Thus, the refill period is conservatively neglected in the mass and energy release calculation.
3. Reflood - begins when the water from the lower plenum enters the core and ends when the core is completely quenched.
4. Post-Reflood (Froth) - describes the period following the reflood transient. For the pump suction break, a two-phase mixture exits the core, passes through the hot legs, and is superheated in the steam generators. After the broken loop steam generator cools, the break flow becomes two phase.

Generic studies have been performed with respect to the effect on the LOCA mass and energy releases relative to postulated break size. The double-ended guillotine break has been found to be limiting due to larger mass flow rates during the blowdown phase of the transient. During the reflood and froth phases, the break size has little effect on the releases.

Three distinct locations in the reactor coolant system loop can be postulated for pipe rupture.

1. Hot leg (between vessel and steam generator)
2. Cold leg (between pump and vessel)
3. Pump suction (between steam generator and pump)

For long-term considerations the break location analyzed is the double-ended pump suction guillotine break (10.48 ft^2). Pump suction break mass and energy releases have been calculated for the blowdown, reflood, and post-reflood phases of the LOCA. The following information provides a discussion on each break location.

The double-ended hot leg guillotine has been shown in previous studies to result in the highest blowdown mass and energy release rates. Although the core flooding rate would be highest for this break location, the amount of energy released from the steam generator secondary is minimal because the majority of the fluid which exits the core bypasses the steam generators in venting directly to containment. As a result, the reflood mass and energy releases are reduced significantly as compared to either the pump suction or cold leg break locations where the core exit mixture must pass through the steam generators before venting through the break.

For the hot leg break, generic studies have confirmed that there is no reflood peak (i.e., from the end of the blowdown period the releases would continually decrease). The mass and energy releases for the hot leg break have not been included in the scope of this containment integrity analysis because for the hot leg break only the blowdown phase of the transient is of any significance. Since there are no reflood and post-reflood phases to consider, the limiting peak pressure calculated would be the compression peak pressure and not the peak pressure following ice bed meltout.

The cold leg break location has also been found in previous studies to be much less limiting in terms of the overall containment peak pressure. The cold leg blowdown is faster than that of the pump suction break, and more mass is released into the containment. However, the core heat transfer is greatly reduced, and this results in a considerably lower energy release into containment. Studies have determined that the blowdown transient is, in general, less limiting than the pump suction break. During reflood, the flooding rate is greatly reduced and the energy release rate into the containment is reduced. Therefore, the cold leg break is not included in the scope of this analysis.

The pump suction break combines the effects of the relatively high core flooding rate, as in the hot leg break, and the addition of the stored energy in the steam generators. As a result, the pump suction break yields the highest energy flow rates during the post-blowdown period by including all of the available energy of the reactor coolant system in calculating the releases to containment. This break location has been determined to be the limiting break for all ice condenser plants.

In summary, the analysis of the limiting break location for an ice condenser containment has been performed. The double-ended pump suction guillotine break has historically been considered to be the limiting break location, by virtue of its consideration of all energy sources present in the RCS. This break location provides a mechanism for the release of the available energy in the RCS, including both the broken and intact loop steam generators. Inclusion of these energy sources conservatively results in the maximum amount of ice being melted in the event of a LOCA.

14.3.4.3.1 Mass and Energy Release Data

14.3.4.3.1.1 Short Term Mass and Energy Release Data

14.3.4.3.1.1.1 Early Design Analyses (Historical)

The mass and energy release rate transients for all the design cases are given in Figures 14.3.4-133 through 14.3.4-140. All cases are generated with the SATAN-V break model consisting of Moody-Modified Zaloudek critical flow correlations applied at the break element. Since no mechanistic constraints have been established for full guillotine rupture, an instantaneous pipe severance and disconnection is assumed for all transients. Assumptions specific to the early design transients are as follows:

For the hot leg mass and energy release rate transient to loop subcompartments:

Figures 14.3.4-133, -134

1. A double ended guillotine type break.
2. A break located just outside the biological shield.
3. A break located in the worst loop.
4. A six node upper plenum model.
5. A 16 node broken hot leg pipe model.
6. A discharge coefficient (C_D) equal to 1.
7. A 100% power condition with T_{hot} = 606.4°F and T_{cold} = 540.4°F.

For the cold leg mass and energy release rate transient to loop subcompartments:

Figures 14.3.4-135, -136

1. A double ended guillotine type break.
2. A break located just outside the biological shield.
3. A break located in the worst loop.
4. A seven node downcomer model.
5. A 16 node broken hot leg pipe model.
6. A discharge coefficient (C_D) equal to 1.
7. A full power condition with T_{hot} = 606.4°F and T_{cold} = 540.4°F.

For hot leg mass and energy release rate transients to subcompartments:

Figures 14.3.4-137, -138

1. A single ended split type break.
2. A break just outside the hot leg nozzle.
3. A break in the pressurizer loop.
4. A six node upper plenum model.
5. A 16 node broken hot leg pipe model.
6. A discharge coefficient (C_D) equal to 1.
7. Full power condition T_{hot} = 606.4°F and T_{cold} = 540.4°F.

For the cold leg mass and energy release rate transient to subcompartments:

Figures 14.3.4-139, -140

1. A single ended split type break.
2. A break just outside the cold leg nozzle.
3. A break in the pressurizer loop.
4. A seven node downcomer model.
5. A 16 node broken hot leg pipe model.
6. A discharge coefficient (C_D) equal to 1.
7. A full power condition T_{hot} = 606.4°F and T_{cold} = 540.4°F.

For the mass and energy release rate transient to the pressurizer enclosure, a 6 inch spray line pipe break was considered (Figures 14.3.4-141, -142):

1. A guillotine type break modeled as a 0.147 ft^2 split in the cold leg at the pump discharge (area of the six inch pressurizer spray feed line) and a 0.087 ft^2 split in the top of the pressurizer (area of 4 inch spray nozzle).
2. Valves in spray lines are assumed to be open.
3. No pipe resistance for the feed line considered.
4. A full power condition T_{hot} = 606.4°F and T_{cold} = 540.4°F.
5. A discharge coefficient (C_D) equal to 1.

The mass and energy release rate transients for all the generated cases are supported by an extensive investigation of short term phenomena. Section 14.3.4.5 includes detailed discussion of the phenomena and the results.

14.3.4.3.1.1.2 Current Design Basis Analyses

Analyses were conducted to support changes in Reactor Power and revised RCS parameters, such as enthalpy, on the mass and energy releases. Details of the subcompartment evaluation are presented in Section 14.3.4.2.5 for the Pressurizer Enclosure Evaluation, Section 14.3.4.2.7 for the Loop Subcompartments Evaluation and, Section 14.3.4.2.8, for the Reactor Cavity Evaluation.

14.3.4.3.1.2 Long Term Mass and Energy Release Data

14.3.4.3.1.2.1 Application of Single Failure Analysis

An analysis of the effects of the single failure criteria has been performed on the mass and energy release rates for the pump suction (DEPS) break. An inherent assumption in the generation of the mass and energy release is that offsite power is lost. This results in the actuation of the emergency diesel generators, required to power the safety injection system. This is not an issue for the blowdown period, which is limited by the compression peak pressure.

The limiting minimum safety injection case has been analyzed for the effects of a single failure. In the case of minimum safeguards, the single failure postulated to occur is the loss of an emergency diesel generator. This results in the loss of one pumped safety injection train, thereby minimizing the safety injection flow. As additional conservatism has been included in this analysis in that the closure of the RHR crosstie valve has been considered because it results in a further reduction in safety injection flow. The analysis further considers the RHR and SI pump head curves to be degraded by 15% and the charging pump head curve to be degraded by 10%. This results in the greatest SI flow reduction for the minimum safeguards case.

14.3.4.3.1.2.2 Blowdown Mass and Energy Release Data

The SATAN-VI code is used for computing the blowdown transient, and is the same as that used for the February 1978 ECCS calculation (Reference 32). The methodology for the use of this model is described in Reference 22.

Table 14.3.4-41 presents the calculated mass and energy releases for the blowdown phase of the DEPS break. For the pump suction breaks, break path 1 in the mass and energy release tables refers to the mass and energy exiting from the steam generator side of the break; break path 2 refers to the mass and energy exiting from the pump side of the break.

The mass and energy releases for the double-ended pump suction break, given in Table 14.3.4-41, terminate 26.4 seconds after the postulated accident.

14.3.4.3.1.2.3 Reflood Mass and Energy Release Data

The WREFLOOD code used for computing the reflood transient, is a modified version of that used in the ECCS calculation (Reference 32). The methodology for the use of this model is described in Reference (22).

The WREFLOOD code consists of two basic hydraulic models - one for the contents of the reactor vessel, and one for the coolant loops. The two models are coupled through the interchange of the boundary conditions applied at the vessel outlet nozzles and at the top of the downcomer. Additional transient phenomena such as pumped safety injection and accumulators, reactor coolant pump performance, and steam generator release are included as auxiliary equations which interact with the basic models as required. The WREFLOOD code permits the capability to calculate variations during the core reflooding transient of basic parameters such as core flooding rate, core and downcomer water levels, fluid thermodynamic conditions (pressure, enthalpy, density) throughout the primary system, and mass flow rates through the primary system.

The code permits hydraulic modeling of the two flow paths available for discharging steam and entrained water from the core to the break; i.e., the path through the broken loop and the path through the unbroken loops.

A complete thermal equilibrium mixing condition for the steam and emergency core cooling injection water during the reflood phase has been assumed for each loop receiving ECCS water. Even though the Reference 22 model credits steam/mixing only in the intact loop and not in the broken loop, justification, applicability, and NRC approval for using the mixing model in the broken loop has been documented (Reference 33). This assumption is justified and supported by test data, and is summarized as follows:

The model assumes a complete mixing condition (i.e., thermal equilibrium) for the steam/water interaction. The complete mixing process, however, is made up of two distinct physical processes. The first is a two phase interaction with condensation of steam by cold ECCS water. The second is a single phase mixing of condensate and ECCS water. Since the steam release is the most important influence to the containment pressure transient, the steam condensation part of the mixing process is the only part that need be considered. (Any spillage directly heats only the containment sump.)

The most applicable steam/water mixing test data has been reviewed for validation of the containment integrity reflood steam/water mixing model. This data is that generated in 1/3 scale tests (Reference 4), which are the largest scale data available and thus most clearly simulates the flow regimes and gravitational effects that would occur in a PWR. These tests were designed specifically to study the steam/water interaction for PWR reflood conditions.

From the entire series of 1/3 scale tests, a group corresponds almost directly to containment integrity reflood conditions. The injection flowrates for this group cover all phases and mixing conditions calculated during the reflood transient. The data from these tests were reviewed and discussed in detail in Reference (22). For all of these tests, the data clearly indicate the occurrence of very effective mixing with rapid steam condensation. The mixing model used in the containment integrity reflood calculation is therefore wholly supported by the 1/3 scale steam/water mixing data.

Additionally, the following justification is also noted. The post-blowdown, limiting break for the containment integrity peak pressure analysis is the pump suction double-ended rupture break. For this break, there are two flow paths available in the RCS by which mass and energy may be released to containment. One is through the outlet of the steam generator, the other via reverse flow through the reactor coolant pump. Steam which is not condensed by ECCS injection in the intact RCS loops passes around the downcomer and through the broken loop cold leg and pump in venting to containment. This team also encounters ECCS injection water as it passes through the broken loop cold leg, complete mixing occurs and a portion of it is condensed. It is this portion of steam which is condensed that is taken credit for in this analysis. This assumption is justified based upon the postulated break location, and the actual physical presence of the ECCS injection nozzle. A description of the test and test results is contained in References 22 and 23.

Table 14.3.4-42 presents the calculated mass and energy release for the reflood phase of the pump suction double ended rupture with minimum safety injection.

The transients of the principal parameters during reflood are provided in Table 14.3.4-43.

14.3.4.3.1.2.4 Post-Reflood Mass and Energy Release Data

The FROTH code (Reference 21) is used for computing the post-reflood transient.

The FROTH code calculates the heat release rates resulting from a two-phase mixture level present in the steam generator tubes. The mass and energy releases that occur during this phase are typically superheated due to the depressurization and equilibration of the broken loop and intact loop steam generators. During this phase of the transient, the RCS has equilibrated with the containment pressure, but the steam generators contain a secondary inventory at an enthalpy that is much higher than the primary side. Therefore, there is a significant amount of reverse heat transfer that occurs. Steam is produced in the core due to core decay heat. For a pump suction break, a two-phase fluid exits the core, flows through the hot legs and becomes superheated as it passes through the steam generator. Once the broken loop cools, the break flow becomes two-phase. The methodology for the use of this model is described in Reference 22.

After containment depressurization, the mass and energy release available to containment is generated directly from core boiloff/decay heat.

After depressurization, the mass and energy release from decay heat is based on the 1979 ANSI/ANS Standard, shown in Reference 24 and the following input:

1. Decay heat sources considered are fission product decay and heavy element decay of U-239 and Np-239.
2. Decay heat power from fissioning isotopes other than U-235 is assumed to be identical to that of U-235.
3. Fission rate is constant over the operating history of maximum power level.
4. The factor accounting for neutron capture in fission products has been taken from Table 10 of ANS (1979).
5. Operation time before shutdown is 3 years.
6. The total recoverable energy associated with one fission has been assumed to be 200 MeV/fission.
7. Two-sigma uncertainty (2 times the standard deviation) has been applied to the fission product decay.

Table 14.3.4-44 presents the two-phase post reflood (froth) mass and energy release data for the double-ended pump suction break with minimum safety injection. Data for these tables are terminated at the end of froth time, after which the LOTIC code performs its own core boiloff calculation.

14.3.4.3.1.2.5 Sources of Mass and Energy

The sources of mass and energy considered in the LOCA mass and energy release analysis are given in Tables 14.3.4-45 and 14.3.4-46 for the double-ended pump suction break with minimum safety injection.

The mass sources are the reactor coolant system, accumulators, and pumped safety injection. The energy sources include:

1. Reactor coolant system water
2. Accumulator water
3. Pumped injection water
4. Decay Heat
5. Core stored energy
6. Reactor coolant system metal
7. Steam generator metal
8. Steam generator secondary energy
9. Secondary transfer of energy (feedwater into and steam out of the steam generator secondary).

In the mass and energy release data presented, no zirconium-water reaction heat was considered because the clad temperature did not rise high enough for the rate of the zirconium-water reaction heat to be of any significance.

The consideration of the various energy sources in the mass and energy release analysis provides assurance that all available sources of energy have been included in the analysis. Although Cook Nuclear Plant Unit 1 is not a Standard Review Plan Plant, the review guidelines presented in Standard Review Plan Section 6.2.1.3 have been satisfied.

The mass and energy inventories are presented at the following times, as appropriate:

1. Time zero (initial conditions)
2. End of blowdown time
3. End of refill time
4. End of reflood time
5. Time of broken loop steam generator equilibration
6. Time of intact loop steam generator equilibration

The methods and assumptions used to release the various energy sources are given in Reference 22 except as noted in the reflood mass and energy section, which has been approved as a valid evaluation model by the Nuclear Regulatory Commission.

14.3.4.3.1.2.6 Significant Modeling Assumptions

The following assumptions were employed to ensure that the mass and energy releases are conservatively calculated, thereby maximizing energy release to containment:

1. Maximum expected operating temperatures of the reactor coolant system (100% full power conditions)
2. An allowance in temperature for instrument error and dead band (+5.1°F)
3. Margin in volume of 3% (which is composed of 1.6% allowance for thermal expansion, and 1.4% for uncertainty)
4. Core rate thermal power of 3481 MWt (102% of 3413 MWt), which includes a bounding allowance for the MUR power uprate in conjunction with a reduced calorimetric uncertainty.
5. Conservative coefficient of heat transfer (i.e., steam generator primary/secondary heat transfer and reactor coolant system metal heat transfer)
6. Allowance in core store energy for effect of fuel densification
7. A margin in core stored energy (+15 percent included to account for manufacturing tolerances)
8. An allowance for RCS initial pressure uncertainty (+67 psi)
9. Steam generator tube plugging leveling (0% uniform)
   a. Maximizes reactor coolant volume and fluid release
   b. Maximizes heat transfer area across the SG tubes
   c. Reduces coolant loop resistance, which reduces delta-p upstream of the break, and increases break flow

Thus based on the above conditions and assumptions, the LOCA mass and energy release calculation for the D.C. Cook Nuclear Plant was completed based upon a composite analysis. This composite analysis uses bounding conditions applicable as a single analysis to bound both Unit 1 and Unit 2.