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 accident (LOCA).

The containment system receives mass and energy releases following a postulated rupture in the RCS. These releases continue over a time period, which, for the LOCA mass and energy analysis, is typically divided into four phases:

1. **Blowdown:**
   The period of time from accident initiation (when the reactor is at steady state operation) to the time that the lower plenum begins to re-pressurize after initial coolant evacuation.

2. **Refill:**
   The period of time when the reactor vessel lower plenum is being filled by accumulator and ECCS water. The WCOBRA/TRAC code mechanistically calculates this phase.

3. **Reflood:**
   The period of time that begins when the water from the reactor vessel lower plenum enters the core and ends when the core is completely quenched.

4. **Post-Reflood:**
   The period of time following the reflood phase. It is during this portion of the transient that (for the DECL and DEPS breaks) a two phase mixture exiting the core enters the steam generators, resulting in reverse heat transfer from the secondary side to the primary side. Heat transfer from the steam generator secondary metal to the fluid, and then from the fluid to the tubes, is accounted for in a mechanistic fashion.

The WCAP-17721-P [23] methodology uses a single code for all phases of the LOCA transient through the time of peak containment pressure.

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)

Using the WCAP-17721-P WCOBRA/TRAC methodology [23], full double ended ruptures were analyzed in the cold leg and the pump suction leg, each with 1 and 2 trains of safety injection, to cover the spectrum of possible limiting break locations for D. C. Cook Unit 1 in the context of the new methodology.

Full double ended ruptures of the cold leg and pump suction leg behave similarly, or more specifically, both behave dissimilarly from a double ended rupture of the hot leg. This is because the hot leg break provides a direct vent path to containment for the core exit flow during the post-blowdown phases. This has the effect of allowing the two phase mixture to bypass the steam generators, yielding significantly reduced integrated energy release in the long term. While the blowdown has the potential to be more severe for the hot leg break, ice condenser plants are inherently limited by the long term mass and energy releases after the ice bed is depleted. Therefore, the hot leg break has been excluded from the spectrum of runs. The double ended pump suction and double ended cold leg breaks both provide a mechanism to transport a two phase mixture to both the intact and broken steam generators, and so both have been analyzed with WCOBRA/TRAC.

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 DECL 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. 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 Mass and Energy Release Data

WCOBRA/TRAC consists of two primary source codes, COBRA-TF and TRAC-PD2. COBRA-TF is a three dimensional thermal hydraulic code that is used to model the vessel in detail, and TRACPD2 is a one dimensional code that is used to model loop piping, pumps, steam generators, and various boundary conditions. The WCOBRA/TRAC computer code is currently used as the PWR ECCS evaluation model by Westinghouse; it is fully capable of calculating the thermal/hydraulic RCS response to a large pipe rupture. The use of WCOBRA/TRAC for this application has been qualified by comparison with scalable test data covering the expected range of conditions and important phenomena. Modifications to WCOBRA/TRAC were required to model the specifics of importance to the LOCA M&E analysis, and these updates are discussed below.

The WCOBRA/TRAC steam generator, modeled in accordance with the ECCS evaluation model, was shown to over predict the reverse heat transfer from the steam generators. Updates were made to more accurately calculate the steam generator cool down. These updates were validated by comparison to FLECHT-SEASET steam generator separate effects tests. The result is a computer code capable of modeling phenomena associated with the large break LOCA conditions that provides significant margin relative to the current WCAP-10325-P-A [22] methodology because the stored RCS and SG energy is released at a mechanistically calculated rate instead of forced out over a conservatively short duration.

Beginning with the peak clad temperature (PCT) D. C. Cook Unit 1 model, specific updates were made to the model to bias it for containment integrity purposes. These key updates included:

1. Updated the PCT noding structure to include safety injection and accumulator injection in all loops
2. Maximized the RWST temperature (105°F, technical specification maximum)
3. Applied accumulator upper limit pressure (672.7 psia), lower limit liquid volume (921 ft3), and maximum temperature (120°F)
4. RCS volume was increased by 3% for thermal expansion and measurement uncertainty
5. SG tube plugging level was reduced to 0% (assumption maximizes RCS volume and flow/heat transfer area of SG tubes)

6. Increased the RCS temperatures to the high end of the operating range band and included uncertainty for a target T_{avg} of 580.5°F
7. Increased the RCS initial pressure to 2317 psia (including uncertainties)
8. Increased the pressurizer liquid level, targeting maximum water volume of 1215 ft^3
9. Increased core power to account for uncertainty at full power, targeting 3317 MWt
10. Applied ANS 1979 + 2σ decay heat
11. Turned off fuel rod swelling model
12. Used Baker-Just correlation for metal/water reaction
13. Updated the steam generator noding structure per WCOBRA/TRAC M&E methodology
14. Biased the steam generator secondary side volumes high by 3% to account for uncertainty

The resulting model was used to calculate the mass and energy releases for the limiting break scenario, a double ended cold leg break with minimum safeguards. The WCOBRA/TRAC tool calculates all phases of the peak pressure LOCA transient, including blowdown, refill, reflood, and post reflood long term. The resulting blowdown and post blowdown mass and energy releases are found in Table 14.3.4-41 and Table 14.3.4-42, respectively.

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

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. The highest decay heat release rates come from the fission of U-238 nuclei. Thus, to maximize the decay heat rate a maximum value (8%) has been assumed for the U-238 fission fraction.
2. The second highest decay heat release rate comes from the fission of U-235 nuclei. Therefore, the remaining fission fraction (92%) has been assumed for U-235.

3. The factor which accounts for neutron capture in fission products has been taken directly from Table 10 of the standard.
4. The number of atoms of Pu-239 produced per second has been assumed to be 70% of the fission rate.
5. The total recoverable energy associated with one fission has been assumed to be 200 MeV/fission.
6. The fuel has been assumed to be at full power for 108 seconds.
7. 2σ uncertainty has been applied to the fission product decay. This accounts for a 98% confidence level.

14.3.4.3.1.2.3 (deleted)

14.3.4.3.1.2.4 (deleted)

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 provided below for the double-ended cold legbreak 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 (including the steam generator tube metal)
7. Steam generator metal (including the shell, wrapper, and internals)
8. Steam generator secondary fluid energy (liquid and steam)

All sources of mass and energy listed above are considered in the WCOBRA/TRAC portion of the analysis. The water in the RCS, accumulators, safety injection boundary conditions, and SG secondary is explicitly modeled. Core decay heat (including feedback effects during blowdown) is included in the WCOBRA/TRAC fuel rod model. The fuel rod model also includes an energy term to represent core stored energy. The reactor coolant system (RCS) and steam generator

(SG) metal, and the associated heat transfer from these sources, is modeled in the WCOBRA/TRAC analysis.

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 methods and assumptions used to release the various energy sources are given in Reference 22, 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. The RCS volume was increased by 3% (composed of a 1.6% allowance for thermal expansion and a 1.4% allowance for uncertainty).
4. Core rate thermal power of 3317 MWt (100.34% of 3306 MWt - conservative compared to licensed power of 3304 MWt).
5. Steam generator secondary side mass was biased conservatively high.
6. Initial fuel temperatures, and thus the core stored energy, were based on late in life conditions that included the effects of fuel pellet thermal conductivity degradation.
7. A maximum containment backpressure equal to design pressure.
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