



UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: i of i</p>
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- 14.3 REACTOR COOLANT SYSTEM PIPE RUPTURE (LOSS OF COOLANT ACCIDENT) 1**
- 14.3.4 Containment Integrity Analysis..... 1**
- 14.3.4.4 Mass and Energy Release Analysis for Postulated Secondary System Pipe Ruptures Inside Containment 1
- 14.3.4.4.1 Short Term Mass and Energy Releases..... 1
- 14.3.4.4.1.1 *Steam Generator Doghouse* 2
- 14.3.4.4.1.2 *Fan Accumulator Room* 3
- 14.3.4.4.2 Long Term Mass and Energy Release Data..... 3
- 14.3.4.4.2.1 *Pipe Break Blowdowns Spectra and Assumptions* 3
- 14.3.4.4.2.2 *Break Flow Calculations* 6
- 14.3.4.4.2.3 *Single Failure Effects*..... 7

UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: 1 of 7</p>
---	--	---

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 Unit 1 is presented in Table 14.1-1. The subsections that follow describe the short-term mass and energy releases, which address 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.

UFSAR Revision 27.0

	INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT	Revised: 27.0 Section: 14.3.4.4 Page: 2 of 7
---	---	--

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 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 ft² 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 ft² 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 ft²) 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 ft², which corresponds to a nominal pipe diameter of 16" with an inside diameter of 14.314".

UFSAR Revision 27.0

	INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT	Revised: 27.0 Section: 14.3.4.4 Page: 3 of 7
---	---	--

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 ft² 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


Steamline break mass and energy releases have been calculated for Unit 1 accounting for the numerous plant changes associated with thimble plug removal (TPR), the measurement uncertainty recapture (MUR) uprate program, and the replacement steam generators (RSGs). The full spectrum of the steamline breaks has been analyzed using the approved methodology in Reference 37 at the licensed NSSS power of 3327 MWt with the BWI-Series 51 RSGs.

14.3.4.4.2.1 Pipe Break Blowdowns Spectra and Assumptions

The following assumptions have been used in the mass and energy release analysis.


- a. Double-ended pipe ruptures are assumed to occur at the discharge nozzle of one steam generator downstream of the integral flow restrictor. Split-pipe breaks are assumed to occur downstream of the discharge nozzle of one steam generator.

UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: 4 of 7</p>
---	--	---

- b. Liquid entrainment in the steam blowdown is modeled for the zero power double-ended rupture. All other double-ended ruptures and the split breaks assume the blowdown is dry saturated steam.
- c. The steamline break protection system design for Unit 1 actuates on a low steam line pressure in 2-out-of-4 loops.
- d. Steamline isolation is assumed complete 11.0 seconds after the setpoint is reached for either low steam line pressure or hi-hi containment pressure. The isolation time allows 3 seconds for electronic delays and signal processing plus 8 seconds for valve closure. The total delay time of 11 seconds for steamline isolation supports the relaxation of the main steam isolation valve (MSIV) closure time.
- e. The break size is limited by the cross-sectional flow area of the BWI Series-51 steam generator integral flow restrictor in the outlet nozzle. 1.4 square-foot double-ended pipe breaks have been evaluated at 100.34 [includes 0.34 percent uncertainty], 70, 30, and zero percent power levels of the MUR uprated 3327 MW NSSS thermal power. Also, at zero percent power, a 1.0 square foot small double-ended pipe break has been evaluated.
- f. Four combinations of steamline ruptures have been evaluated assuming split-pipe ruptures:
 - 1. 0.865 square foot equivalent diameter at 100.34 percent power,
 - 2. 0.857 square foot equivalent diameter at 70 percent power,
 - 3. 0.834 square foot equivalent diameter at 30 percent power,
 - 4. 0.808 square foot equivalent diameter at zero percent power.
- g. Failure of a main steam isolation valve, failure of main feedwater isolation or main feedwater pump trip, and failure of auxiliary feedwater runout control have been considered. Two cases of each break size and power level scenario have been evaluated with one case modeling the MSIV failure and the other case modeling the AFW runout control failure. Each case also assumed continued main feedwater addition to bound the feedwater isolation or main feedwater pump trip failure. Main feedwater isolation via FMO valves is assumed complete 44 seconds after the setpoint is reached for either low steam line pressure or high containment pressure.

UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: 5 of 7</p>
---	--	---


- h. Core residual heat generation is assumed based on the 1979 American Nuclear Society (ANS) decay heat plus 2-sigma model (Reference 24).
- i. The end-of-life shutdown margin is 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.
- j. An end-of-life moderator density coefficient reflecting the most reactive stuck RCCA conditions is assumed.
- k. Minimum capability for injection of boric acid (2350 ppm) solution corresponding to the most restrictive single failure in the safety injection system is assumed. 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, the intermediate-head safety injection system, and the passive accumulators are modeled for the steamline break accident analysis.

The safety injection flowrates assumed in the steamline break analysis corresponds to that delivered by one charging pump and one intermediate-head pump delivering full flow to the cold legs. The safety injection flows assumed in this analysis take into account the degradation of the ECCS charging and intermediate-head pump performance. No credit has been taken for the low concentration borated water, which 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 is assumed.

After the generation of the safety injection signal (appropriate delays for logic, instrumentation, and signal transport included), the appropriate valves begin to operate and the safety injection charging and intermediate-head pumps start. In 27 seconds, the valves are assumed to be in their final positions and the pumps are

UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: 6 of 7</p>
---	--	---

assumed to be at full speed and drawing suction from the RWST. The volume containing the low concentration borated water is swept into the core before the 2350 ppm borated water reaches the core. This delay, described above, is inherently included in the steamline break model.

The modeling of the safety injection system in LOFTRAN is described in Reference 26.

- l. For the at-power cases, reactor trip is available via the safety injection signal, overpower protection (high neutron flux signal or OPAT signal), and the low pressurizer pressure signal.
- m. Offsite power is assumed to be available. Continued operation of the reactor coolant pumps maximizes the energy transferred from the reactor coolant system to the steam generators.
- n. No steam generator tube plugging is assumed to maximize the heat transfer characteristics of the RSGs.

14.3.4.4.2 Break Flow Calculations


- Steam Generator Blowdown

The LOFTRAN computer code (Reference 26) is used to calculate the break flows and enthalpies of the release through the steamline break. Blowdown mass and 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. LOFTRAN has been approved for analysis of steamline break mass and energy releases via Supplement 1 of Reference 37.

- Steam Plant Piping Blowdown

The calculated mass and energy releases include the contribution from the secondary steam piping. For all double-ended ruptures, the steam piping blowdown begins at the time of the break and continues at a uniform rate until the entire piping inventory is released. The flowrate is determined using the Moody correlation, the pipe cross-sectional area, and the initial steam pressure. Following the piping blowdown, flow from the intact steam generators continues to simulate the reverse steam generator flow until steamline isolation for all double-ended ruptures and split breaks.

UFSAR Revision 27.0

	<p style="text-align: center;">INDIANA AND MICHIGAN POWER D. C. COOK NUCLEAR PLANT UPDATED FINAL SAFETY ANALYSIS REPORT</p>	<p>Revised: 27.0 Section: 14.3.4.4 Page: 7 of 7</p>
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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 MSIVs operate, the piping volume capable of blowing down is located between the steam generator and the first isolation valve. If the MSIV fails to close on the affected steam generator, the volume between the break location and the isolation valves in the other steamlines, including the safety and relief valve headers and other connecting lines, will feed the steamline break.
- b. Failure of a diesel generator results 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 main feedwater line, which would not be isolated from the steam generator. The mass in this volume can flash into 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 AFW flowrates entering the steam generator prior to the realignment of the auxiliary feedwater system. The auxiliary feedwater flowrates assumed in the steamline break analysis are a function of the steam generator pressure into which the AFW flows. The auxiliary feedwater flowrates into the steam generator at the break location are twice as high with runout control failure than with no failure of the AFW control.

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