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

14.3.4 Containment Integrity Analysis

14.3.4.1 Containment Structure

14.3.4.1.1 Design Basis

The steel-lined, reinforced concrete containment structure, including foundations, access hatches, and penetrations is designed and constructed to maintain full containment integrity when subjected to accident temperatures and pressures, and the postulated earthquake conditions. Details of the Containment System are described in Chapter 5.

The containment design internal pressure is 12 psig. The effects of pipe rupture in the primary coolant system, up to and including a double-ended rupture of the largest pipe as well as a rupture of the main steam line, are considered in determining the peak accident pressure.

The internal structures of the containment vessel are also designed for subcompartment differential accident pressures. The accident pressures considered are due to the same postulated pipe ruptures as described for the containment vessel.

The other simultaneous loads in combination with the accident pressures, and the applicable load factors, are presented in detail in Chapter 5.

The functional design of the containment is based upon the following accident input source term assumptions and conditions:

1. The design basis accident blowdown mass and energy is put into the containment.
2. The hot metal energy is considered.
3. A reactor core power of 3317 MWt (100.34% of 3306 MWt – conservative compared to licensed power of 3304 MWt) is used for decay heat generation.
4. Minimum Engineering Safety Features performance is assumed based upon the limiting single failure criterion.

The ice condenser is designed to limit the containment pressure below the design pressure for all reactor coolant pipe break sizes up to and including a double-ended severance. Characterizing the performance of the ice condenser requires consideration of the rate of addition of mass and energy to the containment, as well as the total amounts of mass and energy added. Analyses have shown that the accident which produces the highest blowdown rate into the ice condenser containment results in the maximum containment pressure rise. That accident is the double-ended severance of a reactor coolant pipe.

Post-blowdown energy releases can also be accommodated without exceeding the containment design pressure.

14.3.4.1.2 Design Features

The reactor containment is a reinforced concrete structure consisting of a vertical cylinder, a hemispherical dome and a flat base. The interior is divided into three volumes, a lower volume which houses the reactor and Reactor Coolant System, an intermediate volume housing the energy absorbing ice bed in which steam is condensed and an upper volume which accommodates the air displaced from the other two volumes during a design basis pipe break accident.

The type of containment used for Donald C. Cook Unit 1 was selected for the following reasons:

1. The Ice Condenser Containment can accept large amounts of energy and mass inputs and maintain low internal pressures and leakage rates. A particular advantage of the ice condenser is its passive design not requiring an actuation signal.
2. The Ice Condenser Containment combines the required integrity, compact size, and carefully considered advanced design desirable for a nuclear station.

Consideration is given to subcompartment differential pressure resulting from a design basis accident. If an accident were to occur due to a pipe rupture in one of these relative small volumes, the pressure would build up at a faster rate than in the containment, thus imposing a differential pressure across the wall of the structure. Section 14.3.4.2, "Containment Subcompartments", presents the subcompartment differential pressure analyses.

The Ice Condenser Containment, incorporating forced circulation of the containment atmosphere together with the containment spray system, ensures the functional capability of containment for as long as necessary following an accident. The peak pressure occurring as the result of the complete blowdown of the reactor coolant through any rupture of the Reactor Coolant System up to and including the hypothetical double-ended severance does not exceed the design pressure of the containment. The design pressure is also not exceeded during subsequent long term pressure transients.

14.3.4.1.3 Design Evaluation

14.3.4.1.3.1 Loss of Coolant Accident

The time history of conditions within an ice condenser containment during a postulated loss-of-coolant accident can be divided into two periods for calculational purposes:

1. The initial reactor coolant blowdown, which for the largest assumed pipe break occurs in approximately 30 seconds.
2. The post blowdown phase of the accident which begins following the blowdown and extends several hours after the start of the accident.

During the first few seconds of the blowdown period following a large rupture of the Reactor Coolant System, containment conditions are characterized by rapid pressure and temperature transients. To calculate these transients a detailed spatial and short time increment analysis is necessary. This analysis is performed with the TMD code with the calculation time of interest extending up to a few seconds following the accident initiation.

Physically, tests at the Waltz Mill ice condenser test facility have shown that the blowdown phase represents that period of time in which the lower compartment air, and a portion of the ice condenser air, are displaced and compressed into the upper compartment and the remainder of the ice condenser. The containment pressure at or near the end of blowdown is governed by this air compression process.

Containment pressure during the post blowdown phase of the accident is calculated with the LOTIC Code, which models the containment structural heat sinks and containment safeguards systems.

The paragraphs that follow describe key physical phenomena considered in the design pressure determination and the containment pressure response analysis. The methods of accounting for these phenomena in the analysis is also discussed.

14.3.4.1.3.1.1 Compression Ratio Analysis

14.3.4.1.3.1.1.a Introduction

Following the initial pressure peak from a double-ended cold leg break, blowdown continues and the pressure in the lower compartment again increases, reaching a peak at or before the end of blowdown. The pressure in the upper compartment continues to rise from beginning of blowdown and reaches a peak, which is approximately equal to the lower compartment pressure.

After blowdown is complete, the steam in the lower compartment continues to flow through the doors into the ice bed compartment and is condensed.

The primary factor in producing this upper containment pressure peak, and, therefore, in determining design pressure, is the displacement of air from the lower compartment into the upper compartment. The ice condenser quite effectively performs its function of condensing virtually all the steam that enters the ice beds. Essentially, the only source of steam entering the upper containment is from leakage through the drain holes and other leakage around crack openings in hatches in the operating deck, which separate the lower and upper portions of the containment building.

A method of analysis of the compression peak pressure was developed based on the results of full scale section tests. This method consists of the calculation of the air mass compression ratio, the polytropic exponent for the compression process, and the effect of steam bypass through the operating deck on this compression.

In the following sections, a discussion of the major parameters affecting the compression peak will be discussed. Specifically they are: air compression, steam bypass, blowdown rate, and blowdown energy.

14.3.4.1.3.1.1.b Air Compression Process Description

The volumes of the various containment compartments determine directly the air volume compression ratio. This is basically the ratio of the total active containment air volume to the compressed air volume during blowdown. During blowdown, air is displaced from the lower compartment and compressed into the ice condenser beds and into the upper containment above the operating deck. It is this air compression process which primarily determines the peak in containment pressure following the initial blowdown release.

The actual Waltz Mill test compression ratios were found by performing air mass balances before the blowdown and at the time of the compression peak pressure, using the results of three full scale special section tests. These three tests were conducted with an energy input representative of the plant design.

In the calculation of the mass balance for the ice condenser, the compartment is divided into two subvolumes; one volume representing the flow channels and one volume representing the ice baskets. The flow channel volume is further divided into four subvolumes, and the partial air pressure and mass in each subvolume are found from thermocouple readings, assuming that the air is saturated with steam at the measured temperature. From these results, the average temperature of the air in the ice condenser compartment is found, and the volume occupied by the air at the total condenser pressure is found from the equation of state as follows:

$$V_a = \frac{M_a R_a T_a}{P} \qquad (1)$$

where:

V_a = Volume of ice condenser occupied by air (ft^3).
M_a = Mass of air in ice condenser compartment (lb.).
T_a = Average temperature of air in ice condenser (°F).
P = Total ice condenser pressure (lb/ft^2).

The partial pressure and mass of air in the lower compartment are found by averaging the temperatures indicated by the thermocouples during the test located in that compartment and assuming saturation conditions. For these three tests, it was found that the partial pressure, and hence the mass of air in the lower compartment, were zero at the time of the compression peak pressure.

The actual Waltz Mill test compression ratio is then found from the following:

$$C_r = \frac{V_1 + V_2 + V_3}{V_3 + V_a} \qquad (2)$$

where:

V_1 = Lower compartment volume (ft^3).
V_2 = Ice condenser compartment volume (ft^3).
V_3 = Upper compartment volume (ft^3).

The polytropic exponent for these tests is then found from the measured compression pressure and the compression ratio calculated above. Also considered is the pressure increase that results from the leakage of steam through the deck into the upper compartment.

The compression peak pressure in the upper compartment for the tests for containment design is then given by:

$$P = P_o (C_r)^n + \Delta P_{deck} \qquad (3)$$

where:

P_o	=	Initial pressure (psia).
P	=	Compression peak pressure (psia).
C_r	=	Volume compression ratio.
n	=	Polytropic exponent.
ΔP_{deck}	=	Pressure increase caused by deck leakage (psi).

Using the method of calculation described above, the compression ratio was calculated for the three full scale section tests. From the results of the air mass balances, it was found that air occupied 0.645 of the ice condenser compartment volume at the time of peak compression, or

$$V_a = 0.645V_2 \quad (4)$$

The final compression volume includes the volume of the upper compartment as well as part of the volume of air in the ice condenser. The results of the full scale section tests (Figure 14.3.4-1) show a variation in steam partial pressure from 100% near the bottom of the ice condenser to essentially zero near the top. The thermocouples and pressure detectors confirm that at the time when the compression peak pressure is reached steam occupies less than half of the volume of the ice condenser. The analytical model used in defining the containment pressure peak uses the upper compartment volume 64.5 percent of the ice condenser air volume as the final volume. This 64.5 percent value was determined from appropriate test results.

The calculated volume compression ratios are shown in Figure 14.3.4-2, along with the compression peak pressures for these tests. The compression peak pressure is determined from the measured pressure, after accounting for the deck leakage contribution. From the results shown in Figure 14.3.4-2, the polytropic exponent for these tests is found to be 1.13.

For the long-term containment integrity analysis, the compression pressure is used to initialize the calculations.

The Donald C. Cook volume compression ratio, not accounting for the dead ended volume effect, is calculated using Equation 2 and using data from Table 14.3.4-1. The Table 14.3.4-1 containment compartment volume data have been adjusted, per the analysis methodology, to conservatively bias the analysis (References 35 & 36). Using the following volume information:

$V_1 = 293{,}801 \text{ ft}^3$
$V_2 = 110{,}520 \text{ ft}^3$
$V_3 = 727{,}628 \text{ ft}^3$

the compression ratio becomes:

$$C_r = \frac{1{,}131{,}949}{727{,}628 + 0.645 * 110{,}520} = 1.42$$

The peak compression pressure, based on an initial containment pressure of 15.0 psia, is then given by Equation 3 as:

$$P_3 = 15.0\ (1.42)^{1.13} + 0.4 = 22.64 \text{ psia or } 7.94 \text{ psig}$$

The peak compression pressure in the upper compartment for D.C. Cook Unit 1 design is 7.94 psig. This peak compression pressure includes a pressure increase of 0.4 psi from steam bypass. The nitrogen partial pressure from the accumulators is not included, since it is not added to the containment atmosphere until after the compression peak has passed. Accumulator nitrogen is considered in the long-term performance analysis of the containment pressure decay following blowdown, using the LOTIC code.

14.3.4.1.3.1.1.c Sensitivity to Blowdown Energy.

The sensitivity of the upper compartment compression pressure peak versus the amount of energy released is shown in Figure 14.3.4-3. This figure shows the magnitude of the peak compression pressure versus the amount of energy released in terms of percentage of reactor coolant system energy release. These data are based on test results wherein each of the tests were run at 110% and 200% of the initial blowdown rate equivalent to the maximum coolant pipe break flow.

These test results indicate the very large capacity of the ice condenser for additional amounts of energy with only a small effect on compression peak pressure. For example, during testing, 100% energy release gave a pressure of about 6.8 psig, while an increase up to 220% energy release gave an increase in peak pressure of only about 2 psi. It is also important to note that maldistribution of steam into different sections of the ice condenser would not cause even the small increase in peak pressure that is shown in Figure 14.3.4-3. For every section of the ice condenser that may receive more energy than that of the average section, other sections of the ice condenser would receive less energy than the average section. Thus, the compression pressure in the upper compartment would be indicated by the test performance based on 100% energy release rather than either the maximum energy release section or the minimum energy release section.

Figure 14.3.4-4 gives some insight as to the very large capacity for energy absorption of the ice condenser as obtained from test results. Figure 14.3.4-4 is a plot of the amount of ice melted versus the amount of energy released based on test results at different energies and blowdown rates. These test results indicate that a 200% energy release melts only about 60% of the ice while 100% energy release melts only 30% of the ice. Thus, even for energy release considerably in excess of 200% there would still be a substantial amount of ice remaining in the ice condenser.

14.3.4.1.3.1.1.d Effect of Blowdown Rate

Figure 14.3.4-5 shows the effect of blowdown rate upon the final compression pressure in the upper compartment. Figure 14.3.4-5 is based on the results of a series of tests, all with the plant design ice condenser configuration, but with the important difference that all of these tests were run with 185% of the Reactor Coolant System energy release quantity. There are two important effects to note from Figure 14.3.4-5. One, the magnitude of the compression peak pressure in the upper compartment is low (about 7.8 psig) for the reactor plant design blowdown rate; and two, even an increase in this rate up to 200% blowdown rate produces only a small increase in the magnitude of this peak pressure (about 1 psi).

14.3.4.1.3.1.1.e Effect of Steam Bypass

The method of analysis used to obtain the maximum allowable deck leakage capacity as a function of the primary system break size is presented next. Two analyses were used to demonstrate the margin between the original design leakage value of 5 ft^2 and the maximum allowable. Considering the current design basis value of 7 sq. ft. for the deck leakage, the following discussion remains valid.

During the blowdown transient, steam and air will flow through the ice condenser doors and also through the deck bypass area into the upper compartment. For the containment the bypass area is composed of two parts, a known leakage area of 2.2 ft^2 with a geometric loss coefficient of 1.5 through the deck drainage holes location at the bottom of the refueling cavity, and an undefined deck leakage area with a conservatively small loss coefficient of 2.5. Leakage through the backdraft damper of the air return fans was determined to be 0.18 sq. ft./damper and was considered in the known leakage area. For the CEQ Fan Ventwell and Stairwell drains, the identified divider barrier bypass area is increased by approximately 0.16 ft^2 as a result of the removal of the check valve internals.

A resistance network similar to that used in TMD is used to represent 6 lower compartment volumes, each with a representative portion of the deck leakage and the lower inlet door flow resistance adjacent to the lower compartment element. The inlet door flow resistance and flow area are calculated for small breaks that would only partially open these doors.

The coolant blowdown rate as a function of time is used with this flow network to calculate the differential pressures on the lower inlet doors and across the operating deck. The resultant deck leakage rate and integrated steam leakage into the upper compartment are then calculated. The lower inlet doors are initially held shut by the cold head of air behind the doors (approximately 1/2 - 1 pound per square foot). The initial blowdown from a small break opens the doors and removes the cold head on the doors. With the door differential pressure removed the door position is slightly open. An additional pressure differential of one pound per square foot is then sufficient to fully open the doors. The nominal door opening characteristic are based on test results.

The first analysis conservatively assumed that flow through the postulated leakage paths is pure steam. During the actual blowdown transient, steam and air representative of the lower compartment mixture would leak through the holes; thus less steam would enter the upper compartment. If flow were considered to be a mixture of liquid and vapor, the total leakage mass would increase but the steam flow rate would decrease. The analysis also assumed that no condensing of the flow occurs due to structural heat sinks. The peak air compression in the upper compartment for the various break sizes is assumed with steam mass added to this value to obtain the total containment pressure. Air compression for the various break sizes is obtained from previous full scale section tests conducted at Waltz Mill.

The allowable leakage area for the following Reactor Coolant System break sizes was determined: DE, 0.6 DE, 3 ft^2, 8 inch diameter, 6 inch diameter, 2.5 inch diameter, and 0.5 inch diameter. For break sizes 3 ft^2 and above a series of deck leakage sensitivity studies was made to establish the total steam leakage to the upper compartment over the blowdown transient. This steam was added to the air in the upper compartment to establish a peak pressure. Air and steam were assumed to be in thermal equilibrium, with the air partial pressure increased over the air compression value to account for heating effects. For these breaks, sprays were neglected. Reduction in compression ratio by return of air to the lower compartment was conservatively neglected. The results of this analysis are shown in Table 14.3.4-2. This analysis is confirmed by Waltz Mill tests conducted with various deck bypass leakages equivalent to over 50 ft^2 of deck leakage for the double ended blowdown rate.

For breaks 8 inches in diameter and smaller, the effect of containment sprays was included. The method used is as follows: For each time step of the blowdown the amount of steam leaking into the upper compartment was calculated to obtain the steam mass in the upper compartment. This steam was mixed with the air in the upper compartment, assuming thermal equilibrium with air. The air partial pressure was increased to account for air heating effects. After sprays were initiated, the pressure was calculated based on the rate of accumulation of steam in the upper compartment. Reduction in pressure due to operation of the air recirculation fans has been conservatively neglected.

This analysis was conducted for the 8 inch, 6 inch and 2-1/2 inch break sizes assuming two spray pumps were operating (4000 gpm at 80°F). As shown in Table 14.3.4-2, the 8 inch break is the limiting case for this range of break sizes although the 0.6 DE is the limiting case for the entire spectrum of break sizes. With one spray pump operating (2000 gpm at 80°F) the limiting case for the entire spectrum of break sizes is the 8 inch case and results in an allowable deck leakage area of approximately 35 ft^2.

A second, more realistic, method was used to analyze this limiting case. This analysis assumed a 30 percent air, 70 percent steam mixture flowing through the deck leakage area. This is conservative considering the amount of air in the lower compartment during this portion of the transient. Operation of the deck fan would increase the air content of the lower compartment, thus increasing the allowable deck leakage area. Based on the LOTIC Code analysis a structural heat removal rate of over 8000 Btu/sec from the upper compartment is indicated. Therefore a steam condensation rate of 8 lbm/sec was used for the upper compartment. The results indicated that with one spray pump operating and a deck leakage area of 56 ft^2, the peak containment pressure will be below design for the 8 inch case.

The 1/2 inch diameter break is not sufficient to open the ice condenser inlet doors. For this break, either the lower compartment or the upper compartment spray is sufficient to condense the break steam flow.

In conclusion, it is apparent that there is a substantial margin between the design deck leakage area and that, which can be tolerated without exceeding containment design pressure. This is true for both the original design deck leakage area of 5 sq. ft. and the current design deck leakage of 7 sq. ft.

14.3.4.1.3.1.1.f Effect of Dead-Ended Volumes

In the preceding analysis of the containment compression ratio, it is conservatively assumed that only steam flows into the dead-ended volumes during the reactor coolant system blowdown. There are several dead-ended compartments in the plant containment design which are connected to the lower compartment. The dead-ended volumes considered in the containment integrity analysis are the instrumentation room and the pipe trench. Additional study has shown that the fan accumulator rooms would also act as dead-ended volumes. The storage of air in the dead-ended volumes has the effect of reducing the mass of air stored in the downstream volumes at the time of the compression peak pressure. Since including the dead-ended volumes reduces the calculated peak compression pressure, the results presented for the preceding analysis are conservative. It should be noted that the inclusion of the dead-ended volumes does not affect the magnitude of the second pressure peak, which occurs after the ice condenser has been exhausted, and after the dynamic effects of the blowdown have equalized throughout the containment. The second peak is controlling for plant design, therefore this discussion does not affect the available design margin.

The effect of the including the dead-ended volume was shown to decrease the final peak compression pressure by 0.2 psi. The magnitude of this effect was substantiated by a series of tests at Waltz Mill which were run at a mass compression ratio closely representative of the Cook plant design. Tests were run with and without a dead-ended volume equivalent to 155,000 ft^3 for the containment design. In these tests, the effect of the dead-ended volume was measured to be 0.5 psig, which is equivalent to a 0.32 psi decrease in final peak pressure per 100,000 ft^3 of dead-ended volume. At D.C. Cook, the dead-ended volume has been conservatively calculated to be 61,309 ft^3.

14.3.4.1.3.1.2 Long Term Containment Pressure Analysis

Early in the ice condenser development program it was recognized that there was a need for modeling of long term ice condenser containment performance. It was realized that the model would have to have capabilities comparable to those of the dry containment (COCO Code) model. These capabilities would permit the model to be used to solve problems of containment design and optimize the containment and safeguards systems. This has been accomplished in the development of the LOTIC Code. (Reference 1)

The model of the containment consists of five distinct control volumes, as follows: the upper compartment, the lower compartment, the portion of the ice bed from which the ice has melted, the portion of the ice bed containing unmelted ice, and the dead ended compartments. The ice condenser control volume with unmelted ice is further subdivided into six subcompartments to allow for maldistribution of break flow to the ice bed.

The conditions in these compartments are obtained as a function of time by the use of fundamental equations solved through numerical techniques. These equations are solved for three distinct phases in time. Each phase corresponds to a distinct physical characteristic of the problem. Each of these phases has a unique set of simplifying assumptions based on test results from the Waltz Mill ice condenser test facility. These phases are the blowdown period, the depressurization period, and the long term.

The most significant simplification of the problem is the assumption that the total pressure in the containment is uniform. This assumption is justified by the fact that after the initial blowdown of the Reactor Coolant System, the remaining mass and energy released from this system into the containment are small and very slowly changing. The resulting flow rates between the control volumes will also be relatively small. These small flow rates are unable to maintain significant pressure differences between the compartments.

In the control volumes, which are always assumed to be saturated, steam and air are assumed to be uniformly mixed and at the control volume temperature. The air is considered a perfect gas and the thermodynamic properties of steam are taken from the ASME steam tables.

14.3.4.1.3.1.3 Peak Containment Pressure Transient

The following are the major input assumptions used in the LOTIC analysis for the limiting double-ended cold leg pipe rupture case with the steam generators considered as an active heat source for Donald C. Cook Unit 1 Containment:

1. Minimum safeguards are employed in all calculations, e.g., one of two spray pumps and one of two spray heat exchangers; one of two residual heat removal pumps and one of two residual heat removal heat exchangers with cross-tie valves open providing flow to the core; one of two safety injection pumps and one of two centrifugal charging pumps; and one of two air return fans.

2. 2.2×10^6 pounds of ice initially in the ice condenser which is at 27°F. This temperature assumption maximizes.

3. The blowdown, reflood, and post reflood mass and energy releases described in Section 14.3.4.3 were used.

4. Blowdown and post blowdown ice condenser drain temperatures of 190°F and 130°F are used. (These numbers are based on Reference 2.)

5. Nitrogen from the accumulators in the amount of 4803 pounds is included in the calculations.

6. Essential service water temperature of 88.9°F is used for the spray heat exchanger and the component cooling heat exchanger.

7. The air return fan is effective 300 seconds accident initiation. This is conservative compared to the old value of 132 seconds.

8. No maldistribution of steam flow to the ice bed is assumed.

9. No ice condenser bypass is assumed. (This assumption depletes the ice in the shortest time and is thus conservative.)

10. The initial conditions in the containment are temperatures of 56°F in the upper, 60°F in the lower, 60°F in the dead ended and 27°F in the ice bed volumes. All volumes are at a pressure of 0.3 psig and 15 percent relative humidity, with the exception of the ice bed, which is at 100 percent relative humidity.

11. During the injection phase when the containment spray pumps are taking suction from the RWST, spray pump flow of 1960 gpm is used for the upper compartment and 706 gpm for the lower compartment. During the recirculation phase when the containment spray pumps are taking suction from the recirculation sump, containment spray flow to the upper compartment is 1960 gpm, containment spray flow to the lower compartment is 706 gpm.

12. Operators establish RHR spray no later than 70 minutes following the start of the accident, if the following conditions exist; 1) The Containment Spray System is in operation; 2) fewer than two (2) Containment Spray System (CTS) pumps are operating, and 3) the RHR system has been transferred to cold leg recirculation. The analysis uses the RHR spray flowrate of 1909 gpm.

13. Containment structural heat sink data are found in Table 14.3.4-4, and are assumed with conservatively low heat transfer coefficients, as listed in Table 14.3.4-5.

14. The operation of one containment spray heat exchanger (UA = 2.3 x 10^6 Btu/hr-°F) for containment cooling and the operation of one residual heat removal heat exchanger (UA = 2.2 x 10^6 Btu/hr-°F) for core cooling. The component cooling heat exchanger was modeled at 3.433 x 10^6 Btu/hr-°F.

15. The air return fan returns air at a rate of 39,000 cfm from the upper to lower compartment.

16. A containment sump volume of 72,000 ft^3 is used.

17. The refueling water storage tank is at a temperature of 105°F.

18. A core power of 3317 MWt (100.34% of 3306 MWt – conservative compared to licensed power of 3304 MWt) is used in the calculation (see section 14.3.4.1.1, item 3 of the accident input assumptions and conditions).

19. Credit is taken for cooling of the ECCS water from the RHR heat exchanger during the recirculation mode, starting with the time water is first drawn from the recirculation sump.

20. Essential service water flow to the containment spray heat exchanger was modeled as 2100 gpm. The essential service water flow to the component cooling heat exchanger was modeled as 5000 gpm.

21. The component cooling flow to the RHR heat exchanger was modeled as 5000 gpm.

22. The spurious operation of the upper containment ventilation heaters is included in the model as a 288 kW additional heat input.

With these assumptions, the heat removal capability of the containment is sufficient to absorb the energy releases and still keep the maximum calculated pressure well below design.

The following plots are provided:

- Figure 14.3.4-6, Containment pressure transient.
- Figure 14.3.4-7, Upper compartment temperature transients.
- Figure 14.3.4-8, Lower compartment temperature transients.
- Figure 14.3.4-9, Containment sump temperature transient.
- Figure 14.3.4-10, Ice melt transient.

In addition, Table 14.3.4-6 gives energy accountings at various points in the transient.

The analysis results show that the maximum calculated containment pressure is 10.10 psig, for the double-ended cold leg break minimum safeguards case. This pressure peak occurs at 10859 seconds, with ice bed meltout at 7713 seconds.

Non-condensible hydrogen gas is generated during the limiting design basis LOCA event (i.e. the double ended rupture of a cross-over leg), by several sources: hydrogen that is dissolved in the RCS, hydrogen generated by fuel clad oxidation, radiolysis in the core or by core material that has relocated to the containment sump, and hydrogen generated by corrosion of metal surfaces inside containment. The total hydrogen produced was calculated as a function of time, and the result used to calculate a partial pressure, which is then added to the peak containment pressure. The peak pressure was calculated to increase by 0.1 psig due to non-condensible hydrogen.

Following a LOCA event, the control room operators use the control air system to perform certain recovery and monitoring operations. Given the potential for in-leakage from this system into the containment, the partial pressure from this air must be considered in the peak pressure transient calculation. However, the timing of these remote manual recovery and monitoring operations is not explicitly modeled, so a time-dependent partial pressure transient has not been calculated. Instead, a portion of the containment pressure margin has been allotted to address this air. The control air system leakage will be limited by operator action, such that the effect on containment pressure will be less than 0.1 psi.

The ECCS pumps take suction from the RWST during the injection phase following a LOCA. As RWST volume is injected, the control room operator will transfer the ECCS pump suctions to the recirculation sump. During transfer to recirculation, the component cooling water flow to the RHR heat exchanger is increased. The evaluated impact of up to a 15-minute delay in the increase in CCW flow, during the transfer to recirculation, has an effect on the calculated containment peak pressure of less than 0.04 psi.

A failure of a flexible hose that connects the backup air supply bottles to the pressurizer power operated relief valves (PORVs) will discharge the contents of the air bottles to the containment. The partial pressure from this air must also be considered in the peak pressure transient calculation. The additional effect on containment pressure is calculated as 0.03 psi.

Chapter 5.5.3 describes the upper compartment ventilation units. Following a LOCA event, the spurious operation of the electric heaters in these units has been considered in the containment integrity analysis.

Therefore, when considering the calculated peak containment pressure for the design basis LOCA mass and energy release, including the contribution due to non-condensable hydrogen, control air system leakage, CCW flow during transfer to recirculation, and PORV backup air bottles, the total calculated peak containment pressure is 10.37 psig, which compares favorably to the containment design pressure of 12 psig.

14.3.4.1.3.1.4 Structural Heat Removal

Provision is made in the containment pressure analysis for heat storage in interior and exterior walls. Each wall is divided into a number of nodes. For each node, a conservation of energy equation expressed in finite difference form accounts for transient conduction into and out of the node and temperature rise of the node. Table 14.3.4-4 is a summary of the containment structural heat sinks used in the analysis. The material property data used are found in Table 14.3.4-5.

The heat transfer coefficient to the containment structures is based primarily on the work of Tagami. An explanation of the manner of application is given in Reference (4).

When applying the Tagami correlation, a conservative limit was placed on the lower compartment stagnant heat transfer coefficients. They were limited to 72 Btu/hr-ft^2. This corresponds to a steam-air ratio of 1.4 according to the Tagami correlation. The imposition of this limitation is to restrict the use of the Tagami correlation within the test range of steam-air ratios where the correlation was derived.

14.3.4.1.3.1.5 Relevant Acceptance Criteria

The LOCA mass and energy analysis has been performed in accordance with the criteria shown in the Standard Review Plan (SRP) section 6.2.1.3. In this analysis, the relevant requirements of General Design Criteria (GDC) 50 and 10 CFR Part 50 Appendix K have been included by confirmation that the calculated pressure is less than the design pressure, and because all available sources of energy have been included, which is more restrictive than the old GDC criteria, Appendix H of the original FSAR, to which the Donald C. Cook Plants are licensed. These sources include reactor power, decay heat, core stored energy, energy stored in the reactor vessel and internals, metal-water reaction energy, and stored energy in the secondary system.

Although the Donald C. Cook Nuclear Plant is not a Standard Review Plan plant, the containment integrity peak pressure analysis has been performed in accordance with the criteria shown in the SRP Section 6.2.1.1.b, for ice condenser containments. Conformance to GDC's 16, 38, and 50 is demonstrated by showing that the containment design pressure is not exceeded at any time in the transient. This analysis also demonstrates that the containment heat removal systems function to rapidly reduce the containment pressure and temperature in the event of a LOCA.

14.3.4.1.3.1.6 Conclusions

Based upon the information presented, taking into account modifications made to the containment and ECCS systems and related changes to the accident analysis input assumptions, it has been concluded that operation with the revised plant conditions and increased operating margins for the Donald C. Cook Nuclear Plant is acceptable. Operation with the RHR crosstie valve open was modeled.

The peak containment pressure of 10.37 psig is below the design pressure 12.0 psig. Thus, the most limiting case has been considered, and has been demonstrated to yield acceptable results.

14.3.4.1.3.2 Steam Line Break

Following a steam line break in the lower compartment of an ice condenser plant, two distinct analyses must be performed. The first analysis, the short term pressure analysis, has been performed with the TMD Code. The second analysis, the long term analysis, does not require the large number of nodes which the TMD analysis requires. The computer code which performs this analysis is the LOTIC (Reference 5) Code.

The LOTIC Code includes the capability to calculate the superheat conditions, and has the ability to begin calculations from time zero (References 6, 7, and 8). For all steam line breaks, no re-evaporation is assumed; however, convective heat transfer as detailed in Reference 7 is used. The version of the LOTIC Code that incorporates the above is the LOTIC3 Code (Reference 9). This code was used to perform the steam line break analyses and is the version which has been accepted for this use (References 10 and 11).

14.3.4.1.3.2.1 Peak Containment Temperature Transients

The following are the major input assumptions used in the LOTIC3 steam break analysis:

1. Minimum safeguards are employed; e.g., one of two spray pumps and one of two air return fans.
2. The air return fan is effective 300 seconds after the high-1 containment pressure bistable signal is actuated.
3. A uniform distribution of steam flow into the ice bed is assumed.
4. The total initial ice mass is 2.2×10^6 lbs.
5. The initial conditions in the containment are a temperature of 120°F in the lower and dead-ended volumes, a temperature of 57°F in the upper volume, and a temperature of 27°F in the ice condenser. All volumes are at a pressure of

0.3 psig and a relative humidity of 15%, with the exception of the ice bed, which is at 100% relative humidity.

6. A spray pump flow of 1960 gpm is used in the upper compartment and 706 gpm in the lower compartment. The spray initiation time assumed was 315 sec. after reaching the high-high setpoint.
7. The refueling water storage tank temperature is assumed to be 105°F.
8. ESW is not assumed for the MSLB transient.
9. Containment structural heat sinks as presented in Table 14.3.4-4 were used.
10. The air return fan empties air at a rate of 39,000 cfm from the upper to the lower compartments.
11. The material property data given in Table 14.3.4-5 were used.
12. The mass and energy releases given in Tables 14.3.4-7 and 14.3.4-8 were used, reflecting limiting steam line breaks analyzed for the containment temperature response. Since these rates are considerably less than the RCS double-ended breaks, and their total integrated energy is not sufficient to cause ice bed meltout, the containment pressure transients generated for the previously presented double-ended pump suction RCS break is considerably more severe.
13. The heat transfer coefficients to the containment structures are based on the work of Tagami. An explanation of their manner of application is given in References 4, 6, and 7.
14. The spurious operation of the upper containment ventilation heaters is included in the model as a 288 kW additional heat input.

14.3.4.1.3.2.2 Results

The results of the double-ended steam line break analysis are presented in Table 14.3.4-9. As indicated therein, peak containment temperature results for a number of the doubleended rupture steam line break cases are tightly grouped between 323.7°F and 324.5°F. A typical temperature transient is shown in Figure 14.3.4-11.

The results from the steam line split ruptures (or small breaks) are presented in Table 14.3.4-10. The worst case for these cases is a 0.865 ft^2 split break, occurring ata nominal NSSS power of 3327 MWt and with consideration for a full-power uncertainty of +0.34% and a main steam line isolation valve (MSIV) failure. A temperature transient of this case is presented in Figure 14.3.4-12.

Parametric studies have been performed as part of previous analyses, varying the ice mass between 2.0 and 2.45 million pounds. These previous ice mass parameter studies have shown that the maximum calculated containment temperatures is not sensitive (less than 1°F change) to ice mass over this range.

14.3.4.1.3.2.3 Sensitivity of the Results

The previous section pertains to the steam line break analysis and its subsequent response in identifying the limiting small break. The following evaluation describes additional sensitivity studies of a generic nature, done for smaller breaks up to 0.942 ft^2 at 30% power .

The LOTIC-3 computer code was employed in the generic analysis (Reference 9). The LOTIC-3 computer code was found to be acceptable for the analysis of steam line breaks with the following restrictions (Reference 11):

a. Mass and energy release rates are calculated with an approved model.

b. Complete spectrum of breaks are analyzed.

c. Convective heat flux calculations are performed for all break sizes.

A detailed comparison of the Cook Nuclear Plant characteristics with those of the generic plant can be found in Reference 13.

Figure 14.3.4-13 illustrates a comparison of small break cases, specifically 0.942 ft^2, from Cook Nuclear Plant historical analyses with a similar break from the generic plant small break submittals. The figure shows that the elevated containment temperatures for Cook Nuclear Plant last for a shorter duration than predicted in the transient for the generic plant.

Further, the containment pressure High-2 setpoint, which provides the actuation signal for the containment spray and containment air recirculation fan systems was assumed to be 3.5 psig in the generic analysis. The Safety Analysis Limit (SAL) for the Cook Nuclear Plant High-1 and High 2 containment pressure setpoints are modeled to be 1.75 and 3.5 psig, respectively. In the Cook Nuclear Plant, the fans are started on High-1, and spray is started on High-2 containment pressure signals. Therefore, the actuation setpoint would have been reached sooner in the Cook Nuclear Plant compared to the generic plant, and therefore the containment transient would have been mitigated more rapidly.

Therefore, a generic LOTIC3 spectrum of small breaks analysis is provided here for the Cook Nuclear Plant instead of plant specific analysis. The generic analysis provides the containment responses for a spectrum of small breaks at the 30% power level with assumed failure of the auxiliary feedwater runout protection system. The analyses studied a spectrum of breaks ranging in size from 0.1 ft^2 up to the break identified as the most severe small split break, 0.942 ft^2. The lower bound break size was established in discussions held between the NRC staff and Westinghouse Electric Corporation.

This spectrum included breaks of 0.6, 0.35 and 0.10 ft^2. Figures 14.3.4-14 and 14.3.4-15 provide the upper compartment temperature and lower compartment pressure transients. As Figure 14.3.4-16 shows, similar lower compartment temperature transients were calculated for the spectrum of breaks analyzed. However, the 0.6 ft^2 break resulted in a slightly higher maximum lower compartment temperature (see Table 14.3.4-11). When this transient was compared to the transient identified as the most severe small break at 30% power in the previous analysis, it was found to result in very similar peaks, with the difference being incidental to the results (See Figure 14.3.4-17).

In the generic analysis, spray and fan initiation are automatic after reaching the containment High-2 setpoint. Associated times are included in Table 14.3.4-11. As described above, these times are conservative in regard to the Cook Nuclear Plant, where the containment air recirculation fans are actuated by the High-1 containment pressure bistable signal. Tables 14.3.4-12 and 14.3.4-13 provide the mass and energy release rates for the transients analyzed. These results demonstrate the conservatism of the results previously discussed and also the somewhat insensitive nature of the ice condenser plant containment response to break size.

Table 14.3.4-14 further demonstrates the conservatism of the generic analysis discussed above. The actual plant specific analysis results for the smaller breaks would be similar to the Cook Nuclear Plant results in Figure 14.3.4-13. The temperature would peak, then sharply fall off when the sprays come on, and finally settle to a much lower temperature level for the remainder of the transient.