which are functions of temperature and has the capability to perform a sophisticated fuel-to-clad gap heat transfer calculation. Additionally, the code can perform the necessary calculations to deal with post-DNB transient phenomena such as: film boiling heat transfer correlations, the zirconium-water reaction, and partial melting of the materials.

For the CEA ejection analyses, the nuclear power input is a time-dependent parameter from TWINKLE; however, the input parameters for pressure, flow, temperature and density are maintained at a constant conservative value so as to produce a limiting calculation in FACTRAN.

FACTRAN is further discussed in Reference 3.

3.0 Safety Limits

The real physical limits of this accident are that any consequential damage to either the core or the reactor coolant system must not prevent long-term core cooling and that any offsite dose consequences must be within the guidelines of 10 CFR Part 100. However, the magnitude of fuel failure will be determined by the following limits:

1. The average pellet deposited energy at the hot spot is no greater than 200 cal/gram (clad damage threshold).
2. The centerline enthalpy threshold for incipient melting is no greater than 250 cal/gram.
3. The centerline enthalpy threshold for the fully molten condition is no greater than 310 cal/gram.

The criterion for determining the fraction of fuel rods that will release their radioactive fission products during the CEA ejection is the one quoted above for determining clad damage.

4.0 References

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2. Risher, D. H., Jr. and Barry, R. F., "TWINKLE - A Multi-Dimensional Neutron Kinetics Computer Code," WCAP-7979-P-A, January 1975 (Proprietary) and WCAP-8028-A, January 1975 (Non-proprietary).
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REPORT ON THE ANALYSIS METHODS AND EVALUATION MODELS TO BE EMPLOYED IN THE LARGE BREAK AND SMALL BREAK LOCA ANALYSES FOR FORT CALHOUN UNIT 1

WESTINGHOUSE ELECTRIC CORPORATION
SAFETY ANALYSIS TECHNOLOGY
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1.0 INTRODUCTION

This report provides an overview of the Westinghouse Evaluation Models and analysis methodology which will be used to perform Large Break and Small Break LOCA licensing analyses for Fort Calhoun Unit 1.

Previous applications of Westinghouse LOCA methodology to a Combustion Engineering NSSS have relied heavily on the approved Evaluation Models and methods employed for the analysis of Westinghouse plants. Since most of the modeling and methodology is directly applicable to the analysis of a CE NSSS, the licensing precedent has been to directly reference the NRC-approved models and methods used for the analysis of Westinghouse plants. The additional documentation required for licensing the application to a CE NSSS focused primarily on the modifications required to appropriately model the differences between the Westinghouse NSSS and CE NSSS designs, and the differences between the fuel designs for the two systems. This report will assume a similar approach, referencing existing NRC-Approved documentation, where possible, and focusing primarily on addressing plant and fuel difference relative to the LOCA analysis methodology. Section 2.0 of this report contains a description of the CE (specifically Fort Calhoun) plant and fuel design, and the difference from a typical Westinghouse plant and fuel design.

The Large Break LOCA analysis will be performed using a version of the 1981 Evaluation Model with BART/BASH (BASH EM), modified for application to a CE NSSS. The BASH EM has been used for the analysis of Large Break LOCA in numerous licensing applications for Westinghouse fuel in Westinghouse plants. Modifications to the codes which constitute the BASH EM and special modeling methods will be developed and implemented for the analysis of Fort Calhoun Unit 1. Proprietary and Non-proprietary versions of a topical report will be prepared describing the modifications to the BASH EM for CE NSSS. This topical will be provided to the Omaha Public Power District (OPPD) and the Nuclear Regulatory Commission (NRC) in support of the proposed Evaluation Model, analysis methodology and Fort Calhoun specific Large Break LOCA analysis.

The Small Break LOCA analysis will be performed using the NRC-approved Westinghouse Small Break ECCS Evaluation Model Using the NOTRUMP code for the Combustion Engineering NSSS (NOTRUMP EM). The NOTRUMP EM has been used for the analysis of Small Break LOCA in numerous licensing applications for Westinghouse fuel in Westinghouse plants. The version of the NOTRUMP EM developed for the analysis of a CE NSSS has previously been used to perform the Small Break analysis for Millstone Unit 2, which was subsequently reviewed and approved for licensing by the NRC. Some modifications to the previously approved methodology will be implemented for the analysis of Fort Calhoun Unit 1. Proprietary and Non-proprietary versions of a topical report will be prepared describing the modifications to the NOTRUMP EM for CE NSSS. This topical will be provided to OPPD and the NRC in support of the modified analysis methodology and Fort Calhoun specific Small Break LOCA analysis. A discussion of the various codes and modeling features of this model are contained in section 4.0 of this report.

2.0 System Description

The CE NSSS design has been reviewed to ensure the applicability of the models and methodology to be used for the Large and Small Break LOCA analyses. Following is a brief summary of the unique features of the CE NSSS and proposed Fort Calhoun fuel design, highlighting the differences from a typical Westinghouse plant and fuel design.

Loop Layout: The CE design incorporates a system of two hot legs feeding two Steam Generators. The two steam generators feed four cross-over legs (loop seals) attached to four pumps which, in turn, feed four cold legs. The cold leg diameter is slightly smaller than that in a Westinghouse NSSS design, while the hot leg diameter is larger. In addition, the elevation

of the loop seals is near the top of the core elevation, unlike the Westinghouse design, in which the loop seal elevation is near the core midplane.

Control Element Assembly (CEA) Design: The CE design includes a variety of shroud designs for the CEAs. More than one design may be present within a given plant.

Upper Head Bypass/Upper Head Temperature: The CE design provides for negligible bypass flow from the upper downcomer to the upper head, resulting in an upper head temperature very near T_{HOT}.

Core Shroud Bypass: The core shroud region of the CE design differs from the Westinghouse Upflow Barrel/Baffle design in the type of flow paths available and relative flow resistance through the region. For Fort Calhoun, for example, there are no flow holes through the centering plates (horizontal structures) in this region. Slots at the interior edge of the centering plates provide a bypass flow path from lower to upper plenum.

Reactor Coolant Pump: The reactor coolant pump design (single speed vertical shaft centrifugal pumps) for the CE plants are similar to those employed at Westinghouse plants, although the size of the pumps are somewhat smaller.

Steam Generator Inlet Nozzle Angle: The Westinghouse NSSS features a Steam Generator inlet nozzle inclined 40° from vertical, while CE designs have a greater angle of inclination.

Safety Injection/Accumulator Nozzle Angle: As in many Westinghouse plants, the CE design provides for a safety injection line which is connected to the cold leg at angle. For Westinghouse plants, this angle is either 45° or 90°, while this angle is either 60° or 75° from horizontal for the CE designs. The pressure differential due to the interaction of safety injection with steam flow in the cold leg piping is a function of this injection angle.

Safety Injection Tank Pressure: Westinghouse plants feature passive injection tanks (accumulators) with a cover gas pressure on the order of 600 to 700 psig. Some CE designs may include Safety Injection Tanks with a minimum cover gas pressure near 200 psig.

Fuel Assembly Design: The CE fuel assembly design features guide tubes which are several times larger than the Westinghouse 14 x 14 guide thimbles. The one instrumentation tube per assembly is also much larger for the CE design. Grid parameters also vary slightly from the Westinghouse 14 x 14 designs.

Fuel Rod/Pellet Stack Design: The cladding radial dimensions for the Westinghouse designed fuel for a CE NSSS differ somewhat from the Westinghouse designs, including open volumes inside the rod. Also, the active pellet stack height for the CE fuel is often less than the typical 12 foot core length identified with most Westinghouse plants.

3.0 LARGE BREAK LOCA

The Large Break LOCA analysis for Fort Calhoun will be performed using a version of the 1981 Evaluation Model with BART/BASH (BASH EM), modified for application to a CE NSSS. The BASH EM was developed to satisfy the requirements for the analysis of Large Break Loss-Of-Coolant accidents as defined in 10 CFR 50.46[1], and employs the required models and assumptions identified in 10 CFR 50, Appendix K[1]. The BASH EM incorporates components of the earlier 1981 Large Break LOCA ECCS Evaluation Model[2], plus BART technology[3], to which the reflood thermal-hydraulic analysis capability of BASH[4] has been added. The codes used in the BASH EM are SATAN-VI, WREFLOOD, COCO, BASH and LOCBART. While not explicitly part of the BASH series, the BART code has been modified and incorporated for specific application into the BASH and LOCBART codes.

Among these codes, those which were included in the 1981 Evaluation Model (SATAN-VI, WREFLOOD, COCO and LOCTA-IV) have previously been modified for application to a CE NSSS. Changes were made to the 1978 Evaluation Model[5] to 1) introduce new technology based on analytical techniques that had been approved for the modeling of plants with Upper Head Injection (UHI), and 2) incorporate the necessary features appropriate for the analysis of Large Break LOCA for Westinghouse fuel in a CE NSSS.[6] The 1978 EM with the "UHI technology" eventually became the 1981 EM, and the modifications for the application to CE NSSS were approved along with the model improvements for the 1981 EM in the NRC Safety Evaluation Report (SER) which appears in the Proprietary Version of the 1981 EM topical report [5]. The NRC SER for the 1981 Evaluation Model with BART[3] states that the model, "may be applied to PWR's using Westinghouse fuel and which use only cold leg injection", which encompasses the Fort Calhoun Large Break LOCA analysis. However, modifications for the modeling of a CE NSSS have, to date, not been identified and approved for the BASH and LOCBART codes, or for the methodology which constitutes the BASH EM. Proprietary and Non-proprietary versions of a topical report will be prepared describing the modifications to the codes and methodology of the BASH EM for CE NSSS. This topical will be provided to the OPPD and the NRC in support of the proposed Evaluation Model, analysis methodology and Fort Calhoun specific Large Break LOCA analysis.

3.1.1 SATAN-VI

The analysis of the blowdown portion of the Large Break LOCA transient will be performed with the SATAN-VI[7] code. SATAN-VI has previously been modified for application to a CE NSSS as part of the 1981 EM. The primary modifications to this code were 1) the addition of five new elements (47 - 51) to model the intact cold side piping from the Steam Generator outlet plenum to the vessel (4 elements), plus the SIT attached to to the broken loop intact cold leg, and 2) the addition of two elements (52 and 53) to model the CEA shroud flow paths from the Upper Head to the Upper Plenum. A more detailed discussion of these modifications is contained in Reference 6.

3.1.2 WREFLOOD

Prior to the approval of the BASH EM, the WREFLOOD[8] code had been an integral part of the Large Break LOCA Evaluation Model, used for calculating the system thermal-hydraulics for the refill and reflood portions of the Large Break transient. In addition, WREFLOOD was interactively linked to the COCO code providing reflood mass and energy release data for the calculation of the containment pressure transient. With the BASH EM, the BASH code replaces WREFLOOD for the calculation of the reflood system hydraulics. WREFLOOD is still used, however, to calculate the system conditions during the refill portion of the transient, and still interactively provides reflood mass and energy rates to the COCO code.

Two modeling/methodology modifications were incorporated into WREFLOOD for modeling a CE NSSS as part of the 1981 EM. As with SATAN-VI, elements were added to model the intact leg in the broken loop[1] (auxiliary loop).

Because of the difference in the injection angle for Safety Injection flow into the steam-filled cold legs (see Section 2.0), the NRC-specified pressure drops of 0.4 and 1.5 psi for injection angles of 60° and 75°, respectively, are used to model the unrecoverable pressure drop due to steam/water mixing in the Reactor Coolant System (RCS). This feature of the CE NSSS design is accommodated in the WREFLOOD code via input. A more detailed discussion of these modifications is contained in Reference 6.

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1 The intact leg of the broken loop is often referred to as the "auxiliary loop" in Westinghouse documentation for CE NSSS analysis.

3.1.3 COCO

The COCO Code is used to calculate the containment pressure transient during the Large Break LOCA. COCO uses code input, mass and energy information read from the SATAN-VI tape and information on the reflood mass and energy releases provided interactively from WREFLOOD. No modifications (other than plant specific input data) are required to apply COCO to a CE NSSS.

3.1.4 BART

The BART[3] code was developed to provide a more mechanistic calculation of core heat transfer coefficients which had previously been determined from the FLECHT correlation[10] employed in the LOCTA-IV[11] code as part of the 1981 EM. None of the features of the BART code specifically require modification for application to a CE NSSS. With the development of the BART EM, modifications were also added to the WREFLOOD and LOCTA-IV codes for consistency in modeling with BART. The modeling of metal heat release in the vessel downcomer and lower plenum was enhanced from a simple conservative exponential decay to a more mechanistic calculation. The improved version of the WREFLOOD code models the various metal components of the lower plenum as slabs, spheres and cylinders and heat flux to the fluid in these regions is calculated by solving the conduction equation based on the modeled geometries. In addition, the core mass entrainment calculation in WREFLOOD was modified to account for the effect of boiling below the quench front for compatibility with BART methods. This version of the WREFLOOD code is also used in the BASH EM. The BART code is discussed further in Sections 3.1.5 and 3.1.6.

LOCTA-IV was used to perform the rod heat-up calculation in Evaluation Models prior to BASH. The only LOCTA-IV modifications were those required to read data from BART. The rod heat-up calculation will be discussed further in Section 3.1.6.

The BART Evaluation Model was approved for application to PWR's using Westinghouse fuel and which use only cold leg injection by NRC SER which is printed in the Proprietary version of Reference 3. This SER restricts the use of the BART spacer grid model, pending further studies[12]. Aspects of the spacer grid model later received separate approval[13], and are included as part of the BASH EM. Further discussion of fuel grid modeling is contained in Section 3.1.6.

3.1.5 BASH

The BASH code was developed to provide a more mechanistic analysis of the system thermal-hydraulics during the reflood portion of the Large Break LOCA transient previously calculated by the WREFLOOD code. the BASH code is basically a synthesis of two existing codes - NOTRUMP[14] and BART.

NOTRUMP is a nodal transient general network code which offers a more detailed modeling and greater modeling flexibility than the WREFLOOD code. This flexibility allows for an improved modeling of upper plenum mass storage, steam generator heat transfer and loop, resistance during the reflood transient. The non-equilibrium version of the NOTRUMP code[15] is used in the NRC-approved Westinghouse Small Break ECCS Evaluation Model using NOTRUMP[16]. The BASH code is built upon the equilibrium version of this code. The NOTRUMP portion constitutes the loop calculation in the BASH code, and is complemented by a modified version of the BART code which performs the BASH core calculations.

The BART code, described in Section 3.1.4, was modified for modeling an average core during the reflood transient (versus the hot channel modeling used in rod heat-up calculations). The modeling is very similar to that described for the BART code as part of the BART EM, except that thermal-hydraulic and core power conditions are input representing an (core-wide) average channel to model the core reflood. The BART spacer grid model is conservative neglected in the BASH application. Because BASH provides a more mechanistic calculation of the reflooding phenomena, it also demonstrates the oscillatory reflooding behavior predicted by a number of semi-scale tests. The previously described BART model did not have the capacity to handle both positive and negative flows. Therefore, modifications were incorporated into BART to model and numerically solve equations for reverse core flow during reflood. The calculation of void propagation velocities and droplet size (droplet number density) were also modified. Reference 4 provides a detailed description of the BART/NOTRUMP interface.

An additional difference between the BASH methodology and older reflood methodology is directly tied to the core reflooding rate used in the rod heat-up calculations. Due to the oscillatory behavior of reflooding in BASH (which, if modeled explicitly would provide excellent heat transfer beyond that normal conservatisms of the traditional Appendix K approach), flooding rates are not input directly into the rod heat-up calculations. Instead, the oscillatory flooding rate is first undergoes a "smoothing" process which results in a reflooding rate as a representation of step functions used by the rod heat-up calculation. A more detailed description of the flooding rate smoothing procedure is contained in References 4 and 18.

The Proprietary version of Reference 4 contains a copy of the NRC SER approval for the use of the BASH EM for licensing applications. The conclusions of the SER state, "The staff and its consultants have reviewed the topical report its revisions and appendices. We find that it describes an evaluation model acceptable for the licensing analyses of large break loss-of-coolant accidents in Westinghouse plants." On this basis, additional documentation and NRC review will be required for the application of the BART EM to a CE NSSS. Such documentation would describe any modifications required to adequately model the NSSS design and fuel design differences between Westinghouse and CE plants, and justification for the acceptability of models not revised in BASH EM for application to a CE NSSS.

3.1.6 LOCBART

The LOCBART[17, 6] code replaces the LOCTA-IV code for performing the rod heat-up calculations in the BASH EM for Large Break LOCA. LOCBART is a synthesis of two previously approved Large Break LOCA codes, LOCTA-IV and BART. The combination of these codes permits a direct exchange of transient fuel rod temperatures (from LOCTA) and heat transfer coefficients (from BART) at each time step. This is an improvement over the BART EM methodology which required iteration and "hand transfer" of input between the BART and LOCTA-IV codes.

The LOCTA-IV portion of the of LOCBART is the same as that used in the BART EM. The BART portion of the code was modified for the modeling of reverse flow and droplet size as described in Section 3.1.5.

As with BASH, there is currently no licensing documentation supporting the use of the LOCBART code (as part of the BASH EM) for analysis of a CE NSSS. It is however noted that the components of the LOCBART code had previously been modified for CE NSSS analyses,[6] and had been approved for this application.[2, 3]

4.0 SMALL BREAK LOCA

The Small Break LOCA analysis for Fort Calhoun will be performed using a version of the Westinghouse Small Break ECCS Evaluation Model Using the NOTRUMP Code[16] (NOTRUMP EM) as modified for application to a CE NSSS[19]. The NOTRUMP EM will be used to demonstrate compliance with the requirements for the analysis of Small Break Loss-Of-Coolant accidents as defined in 10 CFR 50.46[1], and employs the required models and assumptions identified in 10 CFR 50, Appendix K[1]. Specifically, the NOTRUMP EM was developed to address the requirements of NUREG-0737, Item II.K.3.30.

The NOTRUMP EM consists of the NOTRUMP and LOCTA-IV codes. These codes have previously been modified for application to a CE NSSS. Changes were made to the NOTRUMP EM to incorporate the necessary features appropriate for the analysis of Large Break LOCA for Westinghouse fuel in a CE NSSS, and to address additional Small Break licensing issues not addressed in the Westinghouse version of the NOTRUMP EM. NUREG-0611 addressed NRC concerns regarding Westinghouse NSSS design and the associated Small Break LOCA analysis methods, for which responses were provided in References 15 and 16. The NRC SER on the NOTRUMP code and EM (contained in the Proprietary versions of References 15 and 16, respectively) evaluated the those responses as being adequate. NUREG-0635 addresses concerns similar to those identified in NUREG-0611, but is specific to the CE NSSS design and the associated Small Break LOCA analysis methods. The additional concerns of NUREG-0635, not identified in NUREG-0611 are addressed specifically for the NOTRUMP EM applied to a CE NSSS. The responses to those additional concerns, plus the NRC SER identifying the adequacy of the response are contained in Reference 19.

The NOTRUMP EM, as modified in Reference 19, for the application to CE NSSS has previously been used to perform the licensing basis Small Break LOCA calculation for Millstone Unit 2, demonstrating compliance with 10 CFR 50.46 and NUREG-0737, Item II.K.3.31.

4.1.2 NOTRUMP

The NOTRUMP code is a nodal transient general network code used to model the system thermal-hydraulic transient during the postulated Small Break LOCA. The NOTRUMP code has previously been modified for application to a CE NSSS. The primary modifications to this code and methodology are identified below.

1) The system modeling was modified to accurately represent the CE two hot leg, four cold leg design. The NOTRUMP code uses a generalized input description and thus code modifications were not required to enable modeling of the CE piping geometry. Verification was also provided that the correlations and modeling techniques of the NOTRUMP code would be adequate and applicable for the larger diameter CE hot leg piping. This value is introduced to the code via input and requires no code modification.

2) The difference in Steam Generator inlet nozzle inclination was addressed and appropriate sensitivity studies were performed. Based on comparisons of the flooding constants in the flooding correlation for the two designs, plus the results of the sensitivity studies performed, an appropriate modeling of the CE Steam Generator inlet plenum was defined.

3) The hydraulic behavior of the loop seals during a Small Break LOCA are discussed in Reference 19. Based on this discussion, it is verified that the noding scheme chosen for the analysis, in combination with geometric input representative of a CE NSSS (loop seal design) would adequately model the CE loop seal behavior.

4) The modeling of the flow paths from the Upper Head to the Upper Plenum and geometry of the CEA shrouds are examined in Reference 19. Sensitivity studies were performed to verify that the noding scheme chosen for the analysis, in combination with geometric input representative of a CE NSSS would conservatively model the Upper Head venting during a Small Break LOCA transient.

5) The adequacy of the modeling of the Upper Head bypass flow in the chosen noding scheme is addressed via comparison of the hydraulic resistances of the bypass flow paths in a CE and Westinghouse design. This comparison serves as the basis for the accepted modeling technique and choice of Upper Head fluid temperature.

6) Despite differences in the fuel rod diameter, the steam cooling correlations used in the NOTRUMP code are applicable over a range encompassing both the CE and Westinghouse fuel rod design. Accurate implementation of these correlations for application to the Westinghouse-designed fuel for a CE NSSS is included in the NOTRUMP EM modeling and methodology described in Reference 19.

7) The angle between the cold leg and the safety injection nozzle differ between Westinghouse and CE NSSS designs. Since the angle of the Safety injection jet influences the amount of steam condensation in the loops, the choice of a safety injection angle for the analysis of a CE NSSS is such that loop steam condensation is conservatively modeled.

8) An evaluation of the behavior of the subcooled safety injection (SI) for a CE NSSS design is expected to be similar to that in a Westinghouse NSSS design. Therefore, no modification to the NOTRUMP code was required to accommodate the CE SI geometry.

9) Examination of of data from accumulator (SIT) blowdown tests were used to determine a polytropic expansion coefficient for CE SITs with cover gas pressures of approximately 200 or 600 psig. Based on this examination, a polytropic expansion coefficient was chosen which would be applicable to either of the CE SIT conditions.

10) Based on a comparison of the Reactor Coolant Pump (RCP) design, and comparison with applicable test data, an appropriate pump model was identified for use in NOTRUMP for the analysis of a CE NSSS, as documented in Reference 19.

A more detailed discussion of these modifications is contained in Reference 19.

4.1.2 LOCTA-IV

The LOCTA-IV code is used to perform the rod heat-up calculation for the Small Break LOCA analysis. The LOCTA-IV code is the same code identified in Reference 11, but has been modified slightly to allow consistency with the NOTRUMP output format. The version of LOCTA-IV used in the NOTRUMP EM has also been modified to enhance the modeling of steam cooling and radiation in the rod heat-up calculations. Discussions of these modifications are contained in Reference 16. The primary modifications to this code and methodology are identified below.

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1) Despite differences in the fuel rod diameter, the steam cooling correlations used in the LOCTA-IV code are applicable over a range encompassing both the CE and Westinghouse fuel rod design. Accurate implementation of these correlations for application to the Westinghouse-designed fuel for a CE NSSS is included in the NOTRUMP EM modeling and methodology described in Reference 19.

2) Fuel rod internal crack and dish volumes, normally calculated internal to the code, were replaced with values representative of a CE fuel design, rather than the standard Westinghouse values.

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