ATTACHMENT

DEVELOPMENT OF A GENERIC ECCS EVALUATION MODEL WHICH INCLUDES THE EFFECT OF UPPER PLENUM INJECTION

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DEVELOPMENT OF A GENERIC ECCS EVALUATION MODEL

WHICH INCLUDES THE EFFECT OF UPPER PLENUM INJECTION

1.0 INTRODUCTION

Rochester Gas and Electric (RG&E) intends to address the NRC's concerns identified in Reference 1 by contracting with Combustion Engineering, Inc. to develop a new large break Loss-of-Coolant Accident (LOCA) evaluation model (EM). This model will account for all relevant phenomena associated with the upper plenum injection (UPI) emergency core coolant system (ECCS) of the R. E. Ginna Nuclear Power Plant. The intent of this effort is to replace the current EM used for R. E. Ginna with a new one which will be based on physically meaningful models applicable to UPI. As set forth in Reference 1, the methodology will satisfy all applicable required EM features of 10CFR50 Appendix K, and will be well documented. Experimental model verification and sensitivity studies necessary to support the EM will also be provided.

A summary of the planned effort is outlined in Sections 2 through 6. The Evaluation Model (EM) computer codes are described briefly in Section 2.0. The remainder of this attachment addresses the NRC staff's UPI concerns regarding the need for (1) physically meaningful models (including considering UPI vs. non-UPI plant differences), (2) experimental verification (3) sensitivity studies and (4) adequate documentation. Section 3.0 summarizes the major UPI phenomena and describes the CEUPR (Combustion Engineering Upper Plenum Refill) computer code which will be used to model the UPI refill and reflood phenomena in a physically meaningful manner. Section 4.0 discusses the planned UPI-EM experimental verification effort and Section 5.0 describes the sensitivity studies to be performed to satisfy Appendix K paragraphs I.D.1 and I.D.2. and II.3. The conservatism associated with the EM will be shown following the guidance in SECY-83-472, "Emergency Core Cooling System Analysis Methods" (Reference 16). The documentation to be provided to the NRC is summarized in Section 6.0. The methodology for demonstrating compliance of the new EM to 10CFR50 Appendix K is summarized in Section 7.0.

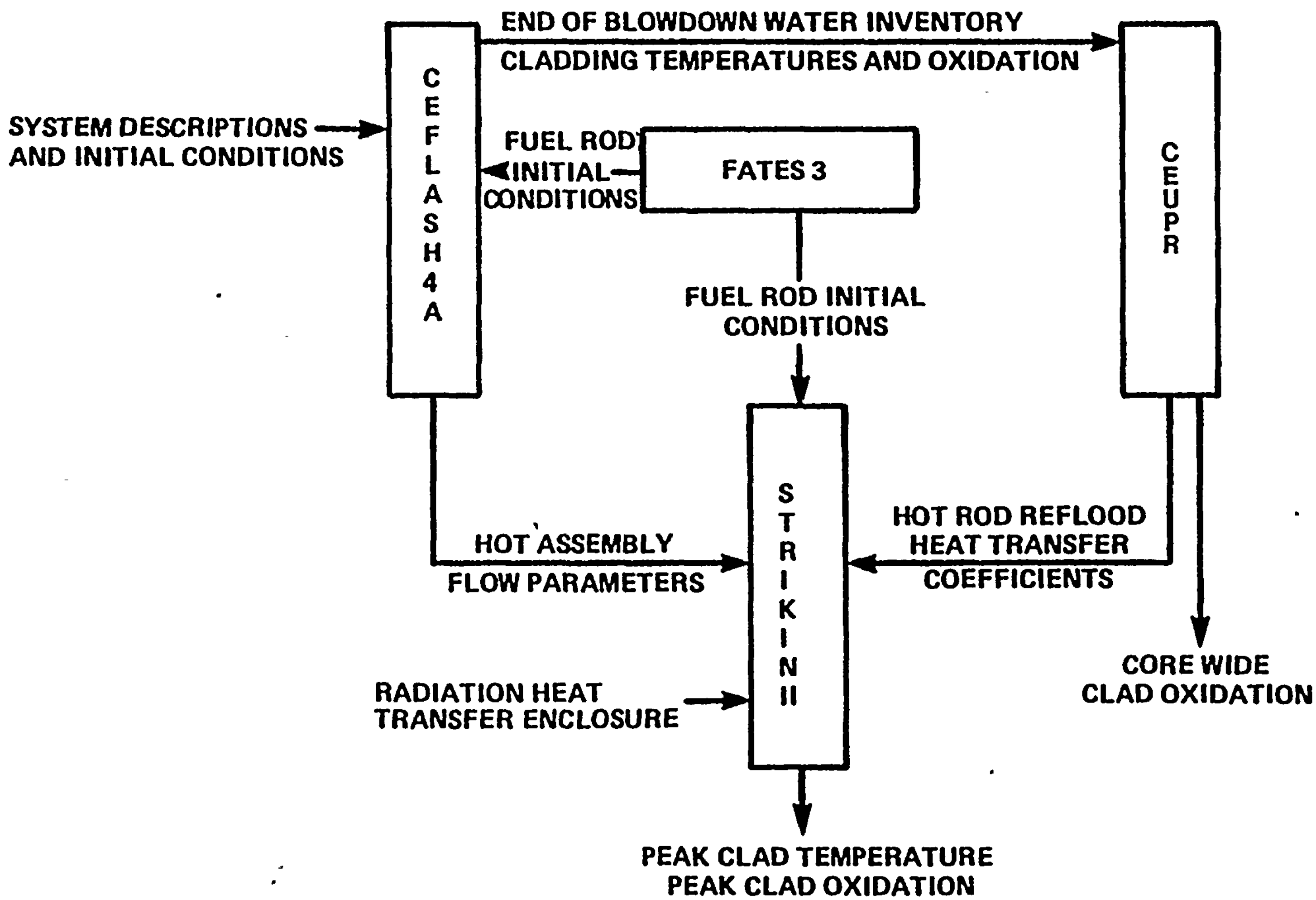
2.0 DESCRIPTION OF THE UPI EVALUATION MODEL

The UPI evaluation model (EM), will use three computer codes to depict the LOCA transient. These codes are CEFLASH-4A, CEUPR and STRIKIN-II. A fourth code, FATES3, provides initial fuel rod conditions. These codes and their interfaces are shown in Figure 1. With the exception of CEUPR, the codes are slightly modified versions of a current NRC approved Evaluation Model. This EM will represent the large break LOCA from the time of the break until after core quench.

2.1 FATES3: Fuel Rod Initial Conditions Model

FATES3 (References 2 and 3) models the complete thermal performance of the fuel rod for a variety of burnup dependent power distributions and power levels. Performance parameters include temperature distributions, gap conductances, fission gas release, pellet and clad dimensional and property changes, and internal gas pressure. FATES3 is approved by the NRC (Reference 4) and is used in licensing analyses. FATES3 has been verified as a predictor of fuel performance through the use of a large variety of experimental data (Reference 3). Verification data includes fuel designed by Combustion Engineering, Westinghouse, Kraftwerk Union, Battelle PNL, and AB Atomenergi.

FIGURE 1
LARGE BREAK LOCA
EVALUATION MODEL
CODE FLOWCHART



This verification is broad enough to justify the application of FATES3 to PWR fuels manufactured by Combustion Engineering, Westinghouse and Exxon.

2.2 CEFLASH-4A: Blowdown Hydraulics

The CEFLASH-4A code is a digital computer program used to calculate the thermal hydraulic response of the reactor coolant system during the blowdown phase of a large break LOCA. The proposed CEFLASH-4A code version to be used for UPI analyses is an extension of the NRC currently approved CEFLASH-4A computer code (References 5 and 6) which will include an enhanced numerics option. The CEFLASH-4A code can be used to perform both best estimate and Appendix K licensing analyses of the blowdown phase of a large break LOCA. The CEFLASH-4A code is a one-dimensional model applicable to any PWR loop arrangement. The code has been verified extensively with integral test comparisons from LOFT and Semiscale experiments and has been used for large break LOCA licensing analyses. CEFLASH-4A is applicable to C-E designed two and three loop plants as well as two, three and four loop Westinghouse designed reactors.

Additional features of CEFLASH-4A include a point kinetics non-linear reactivity feedback model, a detailed heat transfer model for the core including an explicit fuel to cladding gap conductance model, and steam generator and metal wall heat transfer models.

Various break flow correlations are available for use including the Moody model imposed by Appendix K. Alternate critical flow options include the

Henry-Fauske (Reference 7) and Homogeneous Equilibrium models. The decay heat models available include the ANS standard 5.1 (Reference 8) and the Appendix K required model.

CEFLASH-4A also includes models for single phase and two-phase reactor coolant pump performance characteristics and single and two-phase hydraulic pressure losses. The momentum exchange model is complete such that all spatial and temporal variations are treated as required by Appendix K.

2.3. STRIKIN-II: Hot Rod Heatup

The STRIKIN-II code is a digital computer program used to calculate core hot rod transient clad temperatures during blowdown, refill and reflood. The current NRC approved version of STRIKIN-II is described fully in References 9 through 12. The code solves the one-dimensional (axially) conservation of energy equation and the equations of state for the fluid with provisions for local fluid expansion. The calculation of the hot rod heatup during blowdown uses time-dependent functions of blowdown core flow rate, pressure, enthalpy, and heat generation rate from the CEFLASH-4A code.

During refill and reflood STRIKIN-II will be driven by hot channel and hot assembly fluid conditions and heat transfer coefficients supplied by CEUPR. This methodology will replace the FLECHT heat transfer models currently input to STRIKIN-II. The UPI refill/reflood hot pin heatup methodology will be verified against representative experiments.

For a fuel rod, the STRIKIN-II code solves the one-dimensional cylindrical radial heat conduction equation for multiple axial and radial regions along the rod. The conduction model explicitly represents the fuel-cladding gap region and dynamically calculates the gap conductance in each axial region. The gap conductance model is the same as in the FATES-3 code and accounts for:

a) Solid to solid heat conduction pellet to clad if any contact is predicted;
b) Heat conduction through the interfacial gas (separate formulations for Pellet-clad contact and for no contact);
c) Radiation across the gap.

STRIKIN-II also incorporates a model for determining the effect of elastic and plastic clad swelling on surface heat transfer area, gap thickness and gap conductance.

STRIKIN-II explicitly models the zirconium-steam reaction and the incidence of clad swelling and rupture. The zirconium-steam reaction calculation is performed using the integrated form of the Baker-Just equation as required by Appendix K. As an option, the user may select a more realistic model for zirconium-steam reaction for use in non Appendix K hot rod heatup analyses. The clad rupture time, axial location, and ruptured clad geometry are determined directly from an empirical model developed for application to all current zircaloy PWR fuel rod designs.

2.4 CEUPR: Refill and Reflood Hydraulics

CEUPR is a digital computer program being developed for evaluating the reactor vessel refill and core reflood performance of a PWR employing simultaneous upper plenum injection and cold leg injection. CEUPR is being adapted from the WAK (Wiederauffull Kern- "Core Refill") program, which is currently used by KWU for the licensing analyses of German 4-loop PWRs with simultaneous hot and cold side ECC injection systems. CEUPR is intended to specifically account for the plant and ECCS design differences between the German PWRs with hot and cold side injection and the two loop UPI plants (such as R. E. Ginna).

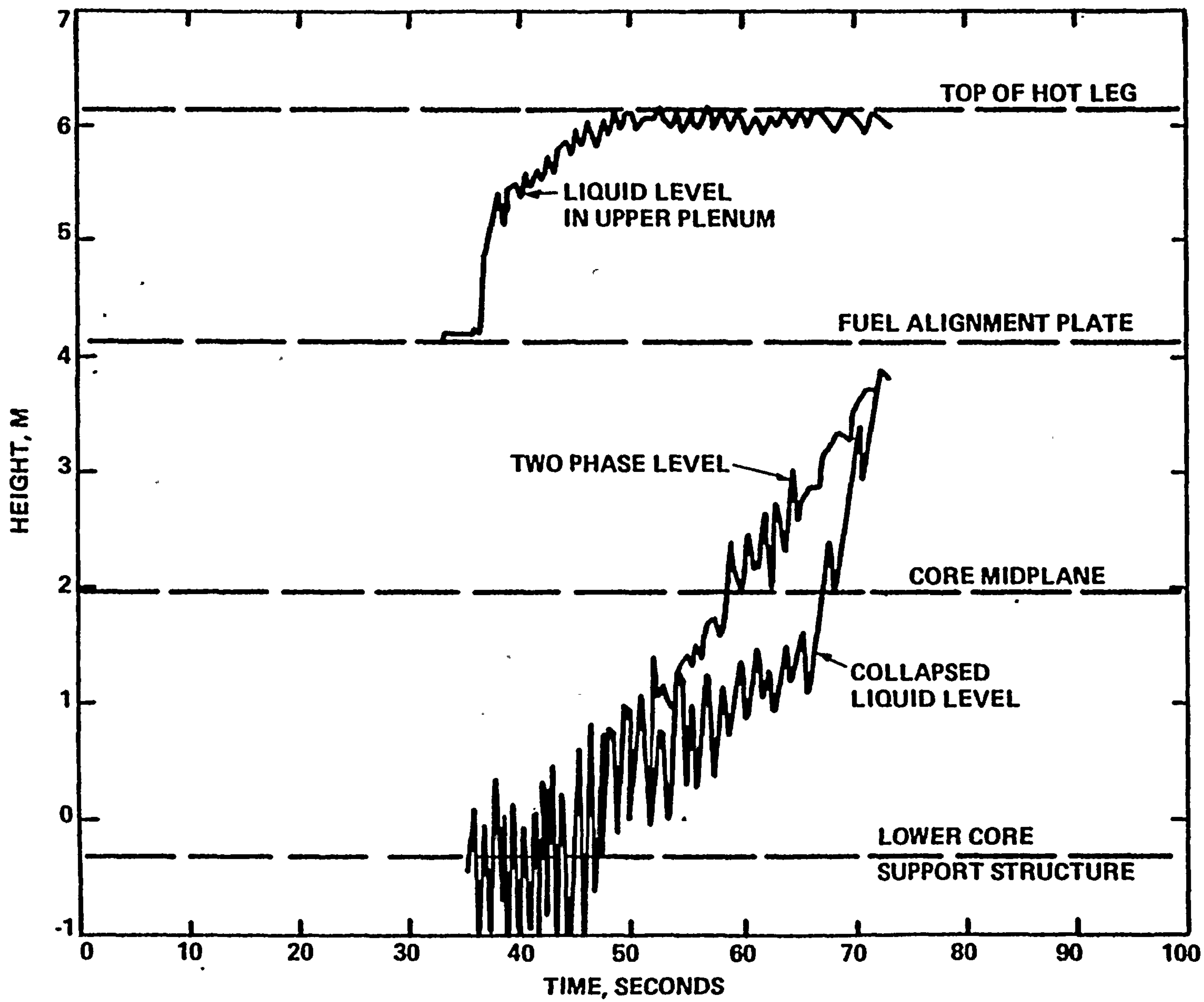
CEUPR accounts for the relevant physical phenomena associated with the UPI plant core refill and reflood process. Significant features of the CEUPR models are listed in Table 1. The most important features are:

- Explicit treatment of the potential water accumulation on the upper core plate (including effects of flooding, entrainment, steam condensation, metal heat transfer, and the hydrostatic head of the water, see Figure 2).
- Flow regime dependent mechanistic core heat transfer model. (This allows a mechanistic treatment of bi-directional core flows and droplet vaporization processes), and
- Explicit calculation of droplet vaporization in the steam generator during reflood (providing a basis for realistically calculating reactor coolant system loop pressure losses).

TABLE 1
CEUPR
MAJOR MODELING FEATURES

- UPPER PLENUM
  - MULTIPLE RADIAL REGIONS
  - ENTRAINMENT (UPI WATER BY STEAM)
  - COUNTERCURRENT FLOW LIMITED AT CORE PLATE
  - WALL HEAT TRANSFER
  - STEAM CONDENSATION
  - LEVEL AND PHASE SEPARATION
- CORE REGION
  - MULTIPLE RADIAL REGIONS
  - CO-CURRENT/COUNTERCURRENT FLOW
  - ENTRAINMENT (FROM LOWER CORE REGION)
  - FLOW REVERSAL AT CORE INLET
  - LEVEL AND PHASE SEPARATION
  - TOP AND BOTTOM QUENCHING OF CORE
  - CONDENSATION AND VAPORIZATION
- HOT LEGS/STEAM GENERATORS
  - HEAT TRANSFER TO STEAM AND WATER
  - ENTRAINMENT FROM HOT LEGS TO STEAM GENERATOR

FIGURE 2
PREDICTED CORE AND UPPER PLENUM LEVELS FOR A REPRESENTATIVE KWU PWR



The predecessor to CEUPR (WAK) has been verified against simultaneous hot side and cold side injection experiments performed at the PKL experimental facility. Verification of CEUPR will be extended to include data comparisons from representative simultaneous hot side and cold side injection experiments performed at the CCTF facility.

An expanded description of the CEUPR refill/reflood computer program is presented in section 3.0.

3.0 PHYSICAL MODELS FOR UPI PLANTS

CEUPR and WAK address, in a physically meaningful way, the physical processes occurring during the refill and reflood periods of PWRs with simultaneous upper plenum and downcomer injection ECCS designs. These physical processes can differ considerably from those occurring in PWRs with only downcomer injection. The more significant of these differences as assessed by PKL and CCTF experiments are:

During Refill:

- o Significant cooling occurs in some regions of the core (particularly the upper core).
- o Upper plenum injection can directly contribute to the lower plenum refill process.

During Reflood:

- o Accumulation of hot side injection water can occur on the upper core plate;
- o Water downflow from the upper plenum into the core region can be intermittent and radially non-uniform;
- o Sustained downward flow can occur out the bottom of the core;
- o Simultaneous upper and lower core quenching occurs;
- o Significant liquid can be entrained into the steam generators;
- o Steam condensation occurs in the upper plenum.

With all of these physical processes included in the CEUPR model, the code will explicitly address 10CFR50 Appendix K Part II paragraph 5 regarding the need for EMs to address physical differences in the plants to which they apply.

3.1 Refill Heat and Mass Transfer

Refill is defined as the period from the end of blowdown until the lower plenum refills to the bottom of the core. For the UPI PWR, the lower plenum refills by the combined accumulation of cold side water penetrating the downcomer and hot side water falling through the core. CEUPR employs a detailed downcomer injection model to account for refill from the cold leg safety injection and a hot side injection model which accounts for emergency coolant (ECC) downflow through the core. The downcomer injection model is based on recent NRC funded research studies on ECC penetration in PWR downcomers (Reference 13) performed by Battelle Columbus Laboratories. The downflow of the ECC water through the core is modeled accounting for effects of core and metal heat transfer, liquid accumulation above the upper core plate (if any), and steam condensation by the injection water. These plenum refill models provide a realistic assessment of the lower plenum refill process and of the time for reflood initiation.

3.2 Reflood Heat and Mass Transfer

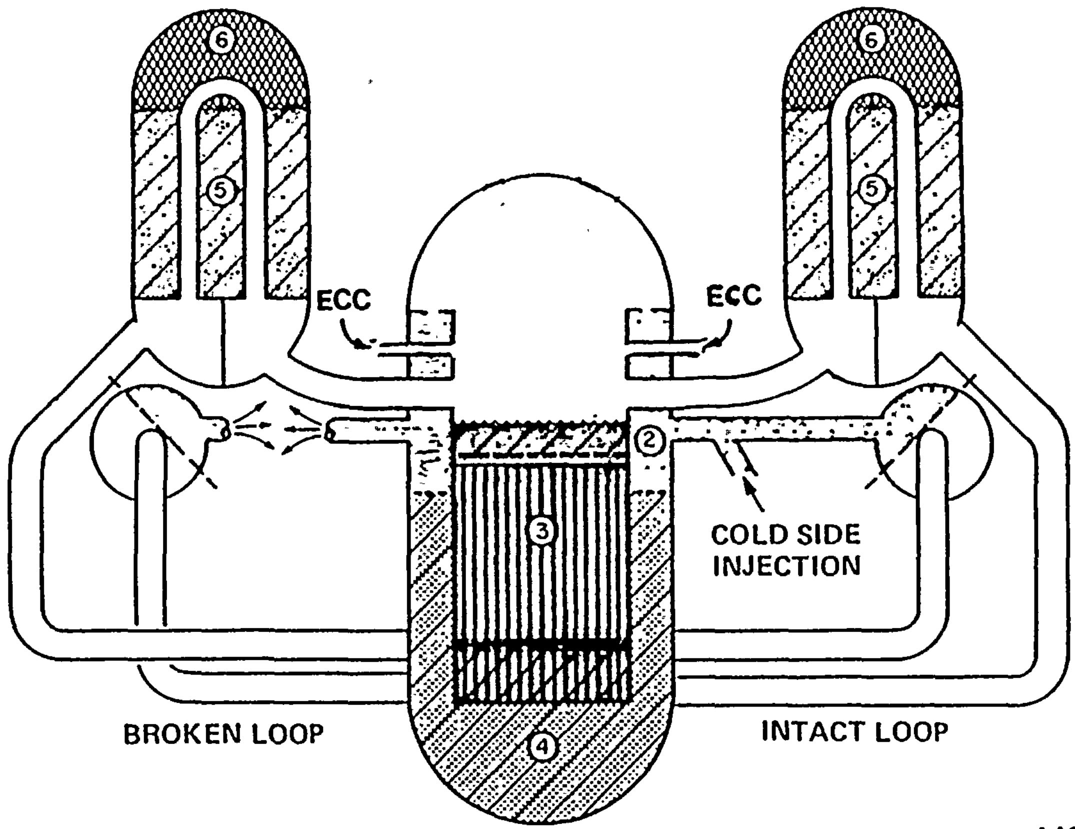
Reflood is initiated once the lower plenum water level reaches the fuel bottom elevation. The reflood process is modeled, using a multi zone simulation of the PWR (see Figure 3). The ability of CEUPR to analyze the UPI reflood transient is embodied in the capabilities of the three major upper plenum injection modeling regions: upper plenum, core and hot leg/steam generator.

3.2.1 Upper Plenum Model

The CEUPR upper plenum model is illustrated in Figure 4. The model is developed to conserve mass and energy in the upper plenum while accounting for the following processes:

1. Steam flow upward through the fuel alignment plate
2. Condensation of upward flowing steam in the upper plenum water pool
3. Upper plenum steam condensation due to injection of ECC water
4. Addition of water entrained from the core to the upper plenum water pool
5. Countercurrent flow through fuel alignment plate
6. Direct addition of ECC water to the upper plenum (UP) water pool

FIGURE 3
CEUPR CONTROL VOLUMES



1 STEAM VOLUME IN UPPER PLENUM & HOT SIDE PIPES BETWEEN SG & RCPs

2 STEAM VOLUME IN DOWNCOMER ABOVE WATER LEVEL

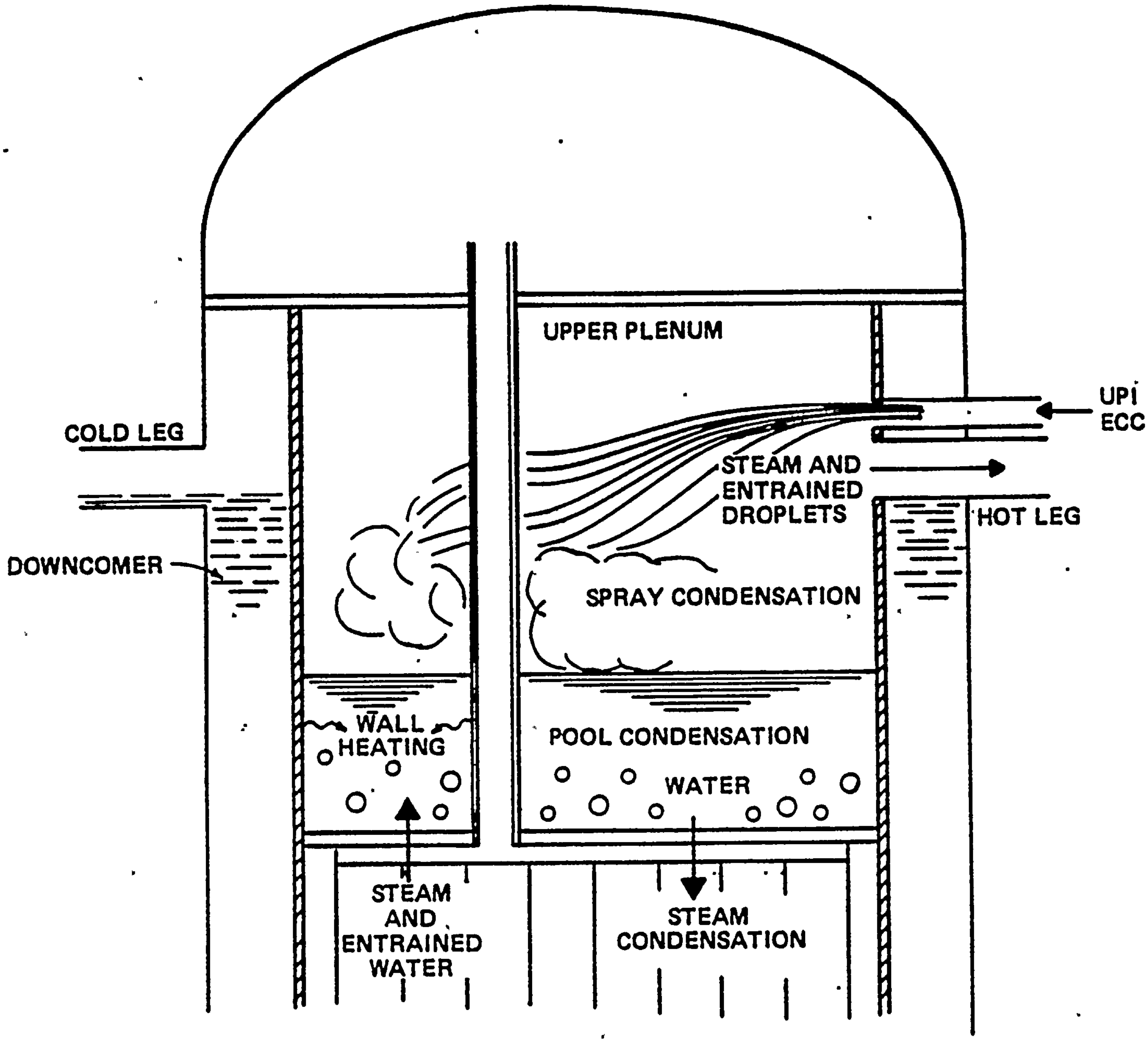
3 VOLUME BETWEEN LOWER EDGE OF ACTIVE CORE AND UP LIQUID LEVEL

4 LIQUID VOLUME IN DOWN-COMER AND LOWER PLENUM

5 WATER VOLUME IN SG (SECONDARY)

6 STEAM VOLUME IN SG (SECONDARY)

FIGURE 4
MODELING OF UPPER PLENUM
CONDENSATION FOR UPPER PLENUM INJECTION



7. Horizontal and vertical water entrainment from UP water pool and UPI water into hot legs and steam generators
8. Pool heating via internal components and core barrel walls

Items 1, 2, 3, 4, and 6 generally result in mass additions to the upper plenum water pool. Items 5, 7, and 8 generally result in upper plenum mass depletions. Nonequilibrium thermodynamics in the upper plenum are modeled by steam-water condensation efficiencies. The hydrostatic head of the water accumulated above the upper core plate is explicitly considered in the primary system pressure balance.

The upper plenum model has a multiregion ECC distribution capability. This feature allows a specified regionwise distribution of injection water. Water downflow into the core is established on a regionwise basis by taking into account countercurrent flow limitations. Water accumulation above the upper core plate is calculated based on conservation of mass and energy with consideration of ECC injection flowrates, countercurrent flow limitations, and the other processes defined above.

3.2.2 Core Model

Core inlet flow is computed on a core average basis by application of the one dimensional unsteady momentum conservation equation. The formulation is derived such that reverse and oscillatory flows at the core inlet plane are permitted so long as the physical processes demand. Core hydrodynamic models account for the effects of two phase level swell and droplet entrainment.

CEUPR allows a multiregion UPI upper plenum model to be coupled to a multiregion core model. Inter-region mixing is permitted provided the steam-water mixture is in a dispersed droplet or steam regime. A uniform froth is maintained below the dispersed droplet regime. Core hydraulics and heat transfer above the uniform froth are quasi-steady.

Core hydraulic conditions are coupled closely to CEUPR heat transfer models. The core hydraulic conditions determines the appropriate fluid properties, void distribution, flow rates and strongly influences selection of the appropriate heat transfer regime. This model provides a realistic procedure for establishing transient fuel rod temperatures and quench front propagation. The need for a mechanistic approach to establish core heat transfer departs from the traditional use of FLECHT based heat transfer correlations (as defined in Section I.D.3 of Appendix K). This departure is consistent with the Appendix K Part II paragraph 5 requirements for the EM to consider significant plant differences.

3.2.3 Hot Leg/Steam Generator

CEUPR employs an explicit representation of primary and secondary side heat transfer in the steam generators and hot legs. This enables the code to compute the degree of droplet vaporization of the two phase mixture as it exits the steam generator. This procedure provides a realistic method of estimating steam binding effects for conditions of significant droplet entrainment.

4.0 EXPERIMENTAL VERIFICATION

With the exception of CEUPR, the proposed methodology will utilize computer codes which are slightly modified versions of NRC approved codes used for large break LOCA analyses (See Reference 15). These approved codes, FATES3, CEFLASH-4A and STRIKIN-II will be justified for application to UPI two loop PWRs. No additional experimental verification for these codes are considered necessary.

CEUPR has been validated in Germany using separate effects reflood heat transfer experiments and with large and small break LOCA combined injection tests performed on the integral PKL test facility. To validate the applicability of CEUPR to a two loop PWR, C-E plans to exercise the code over a range of integral experiments with various upper plenum experimental conditions. Data for evaluation will emphasize UPI and combined injection plant simulations performed on the Cylindrical Core Test Facility (CCTF) (Reference 15). In the process of EM verification, RG&E through its contractor will additionally consider (where appropriate) use of data obtained from various integral and separate effects experimental programs (such as PKL, Semiscale, etc.).

Specific separate effects tests and sensitivity studies will be used to justify model selections for important UPI phenomena (See Section 5.0).

5.0 SENSITIVITY STUDIES

Using the UPI-EM, RG&E through its contractor will perform the required nodalization and time step convergence studies identified in 10CFR50 Appendix K II.2. Studies to define the most limiting large break LOCA condition will also be performed. This later task includes the:

- identification of the most limiting single ECCS failure
- identification of the most limiting break condition
- identification of the most limiting axial power shape
- identification of the most limiting reactor coolant pump condition (on/off).

In accordance with 10CFR50 Appendix K II.3, calculations will be performed demonstrating the sensitivity of the EM to dominant assumed phenomena. Phenomena to be considered for evaluation can include: steam condensation in upper plenum and upper core region, flooding limits at the upper core support plate, core heat and mass transfer, UPI ECC distribution and entrainment, and metal/structure heat transfer.

Following the guidance of Reference 16, experimental verification studies will be used to determine an overall modeling bias and additional sensitivity studies will be performed for the plant to establish the overall 95% uncertainty level of the evaluation model.

6.0 DOCUMENTATION

At the conclusion of the analytical effort a topical report describing the details of the analytical model will be prepared and provided to the NRC staff. The documentation will be prepared in sufficient detail to satisfy the requirements of 10CRF50 Appendix K Parts II a and b.

7.0 SUMMARY

In summary, RG&E proposes to develop a UPI ECCS evaluation model that will satisfy requirements set forth in 10CFR50 Appendix K. As suggested in the NRC guidance (Reference 1) the proposed EM will:

1) Account for UPI plant specific differences
2) Model UPI phenomena in a physically meaningful way.
3) Be verified by appropriate experimental data (as per 10CFR50 Appendix K II)
4) Be supported by appropriate sensitivity and parameter studies (as per 10CFR50 Appendix K II.2. and II.3)
5) Be documented according to the standards set forth in 10CFR50 Appendix K II.1.a. and b.

Finally, the overall level of safety and margin of conservatism associated with the UPI-EM will be demonstrated to be adequate in a manner consistent with the procedure outlined in SECY-83-472 (Reference 16).

8.0 REFERENCES

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