U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

6.2.1.5 MINIMUM CONTAINMENT PRESSURE ANALYSIS FOR EMERGENCY CORE COOLING SYSTEM PERFORMANCE CAPABILITY STUDIES

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of containment integrity

Secondary - None

I. AREAS OF REVIEW

The specific areas of review are as follow:

1. Following a loss-of-coolant accident in a pressurized water reactor (PWR) plant, the emergency core cooling system (ECCS) supplies water to the reactor vessel to reflood, and thereby cool, the reactor core. The core flooding rate is governed by the capability of ECCS water to displace the steam generated in the reactor vessel during the core reflooding period. For PWR plants, core flooding rate depends directly on containment pressure (i.e., the core flooding rate increases with increasing containment pressure). Therefore, as part of the overall evaluation of ECCS performance, the primary reviewer reviews analyses of the minimum containment pressure possible during the time until the core is reflooded following a loss-of-coolant accident (LOCA) to confirm the validity of the containment pressure in ECCS performance capability studies. The primary

Rev. [3] - [Month] 2007

reviewer reviews the assumptions for the operation of engineered safety feature heat removal systems, the effectiveness of structural heat sinks within the containment to remove energy from the containment atmosphere, and such other heat removal processes as steam in the containment mixing with ECCS water spilling from the break in the reactor coolant system; and in ice condenser containments mixing with water from melted ice that drains into the lower containment volume. The review is for all PWR containment types (i.e., dry, subatmospheric, and ice condenser containments).

It should be noted that the minimum containment pressure analysis for ECCS performance evaluation differs from the containment functional performance analysis in that the conservatisms and margins are taken in opposite directions; thus, the minimum containment pressure analysis required by the regulations for ECCS performance evaluation is not conservative as to peak containment pressure in a LOCA and cannot be used to determine the containment design basis.

2. Inspection, Test, Analysis, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the applicant's proposed information on the ITAAC associated with the systems, structures, and components (SSCs) related to this Standard Review Plan (SRP) section is reviewed in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria - Design Certification." The staff recognizes that the review of ITAAC is performed after review of the rest of this portion of the application against acceptance criteria contained in this SRP section. Furthermore, the ITAAC are reviewed to assure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

3. COL Action Items and Certification Requirements and Restrictions. COL action items may be identified in the NRC staff's final safety evaluation report (FSER) for each certified design to identify information that COL applicants must address in the application. Additionally, DCs contain requirements and restrictions (e.g., interface requirements) that COL applicants must address in the application. For COL applications referencing a DC, the review performed under this SRP section includes information provided in response to COL action items and certification requirements and restrictions pertaining to this SRP section, as identified in the FSER for the referenced certified design.

Review Interfaces

The listed SRP sections interface with this section as follows:

1. Section 6.3: coordination with the reviewer responsible for determining the acceptability of the mass and energy release data in the minimum containment pressure analysis. This information is derived from the applicant's evaluation of ECCS performance capability in accordance with 10 CFR 50.46.

2. For COL reviews of operational programs, the review of the applicant's implementation plan is performed under SRP Section 13.4, "Operational Review."

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on the relevant requirements of 10 CFR 50.46, which allows either an acceptable ECCS evaluation model that realistically describes the behavior of the reactor during LOCAs or an ECCS evaluation model developed in compliance with 10 CFR Part 50, Appendix K. The primary reviewer accepts the analysis if it meets the following requirements, as applicable:

1. 10 CFR 50.46(a)(1)(i), with respect to an acceptable ECCS evaluation model that realistically describes the behavior of the reactor during LOCAs or

2. 10 CFR 50.46(a)(1)(ii), with respect to an ECCS evaluation model developed in compliance with 10 CFR 50, Appendix K, paragraph I.D.2, which requires that the containment pressure used for evaluating cooling effectiveness during reflood and spray cooling not exceed pressure calculated conservatively for that purpose.

3. 10 CFR 52.47(a)(1)(vi), as it relates to ITAAC (for design certification) sufficient to assure that the SSCs in this area of review will operate in accordance with the certification.

4. 10 CFR 52.97(b)(1), as it relates to ITAAC (for combined licenses) sufficient to assure that the SSCs in this area of review have been constructed and will be operated in conformity with the license and the Commission's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for review described in Subsection I of this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

Specific criteria that pertain to minimum containment pressure analysis for ECCS performance studies are indicated below:

1. To meet the requirements of 10 CFR 50.46(a)(1)(i), the model to determine minimum containment pressure for ECCS studies should comply with Regulatory Guide (RG) 1.157, Position C.3.12.1, which describes acceptable containment pressure models for ECCS performance analysis.

2. To meet the requirements of 10 CFR Part 50.46(a)(1)(ii), the following specific criteria indicate the conservatism that analyses of the containment response to LOCAs should have for determining the minimum containment pressure for ECCS performance capability studies:

A. Calculations of the mass and energy released during postulated LOCAs should be based on the requirements of 10 CFR Part 50, Appendix K.

B. Branch Technical Position CSB 6-1, "Minimum Containment Pressure Model for PWR ECCS Performance Evaluation," delineates the calculation approach that should be followed for a conservative prediction of the minimum containment pressure.

Technical Rationale

The technical rationale for application of these requirements to reviewing this SRP section is discussed in the following paragraphs:

1. 10 CFR 50.46(a)(1)(i) requires plants to have ECCSs, the cooling performance of which is evaluated for the most severe postulated LOCA. 10 CFR 50.46(a)(1)(i) allows the ECCS evaluation to use a realistic model that describes the behavior of the reactor coolant system during a LOCA. Containment minimum pressure directly affects ECCS performance. Calculation and analysis of this parameter, therefore, is a part of the ECCS performance evaluation. RG 1.157 provides specific methods acceptable to the staff for meeting 10 CFR 50.46(a)(1)(i). This regulation assures that, in a LOCA, the ECCS will perform as predicted, meeting limits on maximum peak cladding temperature, maximum cladding oxidation, and maximum hydrogen generation and maintaining a coolable geometry.

2. 10 CFR 50.46(a)(1)(ii) requires plants to have ECCSs, the cooling performance of which is evaluated for the most severe postulated LOCA. As an alternative to the requirements of 10 CFR 50.46(a)(1)(i), 10 CFR 50.46(a)(1)(ii) requires for the ECCS performance evaluation a model based on 10 CFR Part 50, Appendix K, which provides specific calculation methods for evaluating ECCS performance and significant conservatisms to address the uncertainties of post-LOCA plant behavior. Containment minimum pressure directly affects ECCS performance. Calculation and analysis of this parameter, therefore, is part of the ECCS performance evaluation. This regulation assures that, in a LOCA, the ECCS will perform as predicted, limit maximum peak cladding temperature, maximum cladding oxidation, and maximum hydrogen generation; and maintain a coolable geometry.

III. REVIEW PROCEDURES

The reviewer will select and emphasize material from the procedures described below, as may be appropriate for a particular case.

For each area of review specified in Subsection I of this SRP section, the review procedure is identified below. These review procedures are based on the identified SRP acceptance criteria. For deviations from these specific acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives to the SRP criteria provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

1. Primary review is of the analyses in the safety analysis report of the minimum containment pressure following a LOCA. The reviewer responsible for SRP Section 6.3

confirms the validity of the applicant's mass and energy release data. The primary reviewer evaluates the conservatism of the applicant's assumptions for the operation of containment heat removal systems and the effectiveness of structural heat sinks by comparing the applicant's calculation approach to either the method outlined in Branch Technical Position CSB 6-1 or RG 1.157, Position C.3.12.1 (consistent with Subsection II of this SRP section). In certain cases, the reviewer may perform confirmatory containment pressure response analyses. In these cases, containment pressure calculated by the primary reviewer is compared to that in the applicant's evaluation of ECCS performance capability for assurance of an appropriately conservative value. The primary reviewer advises the SRP Section 6.3 reviewer of the acceptability of the containment back pressure in the ECCS performance evaluation.

2. For reviews of DC and COL applications under 10 CFR Part 52, the reviewer should follow the above procedures to verify that the design set forth in the safety analysis report, and if applicable, site interface requirements meet the acceptance criteria. For DC applications, the reviewer should identify necessary COL action items. With respect to COL applications, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit, or other NRC-approved material, applications, and/or reports.

   After this review, SRP Section 14.3 should be followed for the review of Tier I information for the design, including the postulated site parameters, interface criteria, and ITAAC.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions to be included in the staff's safety evaluation report (SER). The reviewer also states the bases for those conclusions.

The conclusions reached on completion of the review under this SRP section are presented in SRP Section 6.2.1.

For DC and COL reviews, the findings will also summarize (to the extent that the review is not discussed in other SER sections) the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable, and interface requirements and combined license action items relevant to this SRP section.

V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

VI. REFERENCES

1. References for this SRP section as listed in SRP Section 6.2.1.

2. NRC Inspection Manual Chapter IMC-2504, “Construction Inspection Program - Non-ITAAC Inspections,” issued April 25, 2006.

SRP Section 6.2.1.5
Description of Changes

This SRP section affirms the technical accuracy and adequacy of the guidance previously provided in Draft Revision 3, dated April 1996, of this SRP section. See ADAMS accession number ML052070492.

In addition, this SRP section was administratively updated in accordance with NRR Office Instruction LIC-200, Revision 1, "Standard Review Plan (SRP) Process." The revision also adds standard paragraphs to extend application of this updated SRP section to prospective applicant submissions pursuant to 10 CFR Part 52.

The technical changes are incorporated in Revision 3, dated [Month] 2007:

Review Responsibilities - Reflects changes in review branches resulting from reorganization and branch consolidation. Change is reflected throughout the SRP.

I. AREAS OF REVIEW

Reformatted the section with new numbering system. Incorporated reference to 10 CFR Part 52 from draft revision 3 - April 1996. Incorporated generic paragraphs relating to certified designs, ESPs, and COLs.

II. ACCEPTANCE CRITERIA

Reformatted the section with new numbering system. Incorporated reference to 10 CFR Part 52 from draft revision 3 - April 1996. Incorporated generic paragraphs relating to certified designs, ESPs, and COLs.

III. REVIEW PROCEDURES

Reformatted the section with new numbering system. Incorporated reference to 10 CFR Part 52 from draft revision 3 - April 1996. Incorporated generic paragraphs relating to certified designs, ESPs, and COLs.

IV. EVALUATION FINDINGS

None

V. IMPLEMENTATION

None

VI. REFERENCES

None

BRANCH TECHNICAL POSITION CSB 6-1

MINIMUM CONTAINMENT PRESSURE MODEL FOR PWR ECCS PERFORMANCE EVALUATION

I. BACKGROUND

10 CFR Part 50, Appendix K, Paragraph I.D.2, requires that the containment pressure used to evaluate the performance capability of a pressurized-water reactor emergency core cooling system ECCS not exceed a pressure calculated conservatively for that purpose. It further requires the calculation to include the effects of operation of all installed pressure-reducing systems and processes. Therefore, the following branch technical position has been developed as guidance in a minimum containment pressure analysis. The approach described applies only to the ECCS-related containment pressure evaluation pursuant to 10 CFR 50.46(a)(1)(ii) and not to the containment functional capability evaluation for postulated design-basis accidents.

II. BRANCH TECHNICAL POSITION

1. Input Information for Model

   A. Initial Containment Internal Conditions. The minimum containment gas temperature, minimum containment pressure, and maximum humidity encountered under limiting normal operating conditions should be used. Ice condenser plants should use the maximum containment gas temperature.

   B. Initial Outside Containment Ambient Conditions. A reasonably low ambient temperature external to the containment should be used.

   C. Containment Volume. The maximum net free containment volume should be used. This maximum free volume should be determined from the gross containment volume minus the volumes of such internal structures as walls and floors, structural steel, major equipment, and piping. The individual volume calculations should reflect the uncertainty in the component volumes.

   D. Purge Supply and Exhaust Systems. If purge system operation is proposed during the reactor operating modes of startup, power operation, hot standby, and hot shutdown, the system lines should be assumed to be initially open.

2. Active Heat Sinks

   A. Spray and Fan Cooling Systems. The operation of all engineered safety feature containment heat removal systems operating at maximum heat removal capacity (i.e., with all containment spray trains operating at maximum flow conditions and all emergency fan cooler units operating) should be assumed. In addition, the minimum temperature of the stored water for the spray cooling system and the cooling water supplied to the fan coolers, based on technical specification limits, should be assumed.

Deviations from the foregoing are accepted if the worst conditions for a single active failure, stored water temperature, and cooling water temperature can be shown to have been selected from the standpoint of the overall ECCS model.

B. Containment Steam Mixing With Spilled ECCS Water. The spillage of subcooled ECCS water into the containment provides an additional heat sink as the subcooled ECCS water mixes with the steam in the containment. The effect of the steam-water mixing should be considered in the containment pressure calculations.

C. Containment Steam Mixing With Water from Ice Melt. The water from ice melting in an ice condenser containment provides an additional heat sink as the subcooled water mixes with the steam while draining from the ice condenser into the lower containment volume. The effect of the steam-water mixing should be considered in the containment pressure calculations.

3. Passive Heat Sinks

A. Identification. The passive heat sinks that should be included in the containment evaluation model should be established by identifying structures and components within the containment that could influence the pressure response. Structures and components that should be included are listed in Table 1.

Data on passive heat sinks have been compiled from previous reviews and used as a basis for the simplified model outlined below. This model is acceptable for minimum containment pressure analyses for construction permit applications until a complete identification of available heat sinks can be made (*i.e.*, at the operating license review). Where no detailed listing of heat sinks within the containment is provided, the following procedure may model the passive heat sinks within the containment:

(i) Use the surface area and thickness of the primary containment steel shell or steel liner, anchors, and concrete, as appropriate.

(ii) Estimate the exposed surface area of other steel heat sinks in accordance with Figure 1 and assume an average thickness of 9.53 mm (3/8 inch).

(iii) Model the internal concrete structures as a slab with a thickness of 30.5 cm (one foot) and exposed surface of 15,000 m^2 (160,000 ft^2).

Acceptable heat sink thermo-physical properties are shown in Table 2.

Applicants should provide a detailed list of passive heat sinks with appropriate dimensions and properties.

B. Heat Transfer Coefficients. The following conservative condensing heat transfer coefficients for heat transfer to the exposed passive heat sinks during the blowdown and post-blowdown phases of the loss-of-coolant accident should be used:

(i) During the blowdown phase, assume a linear increase in the condensing transfer coefficient from $h_{initial}$ = 8 Btu/hr-ft^2-°F, at t = 0, to a peak value four times greater than the maximum calculated condensing heat transfer coefficient at the end of blowdown, using the Tagami correlation (Reference 2), $h_{max}=72.5(Q/Vt_p)^{0.62}$

where h_{max} = maximum heat transfer coefficient, Btu/hr-ft^2-°F
Q = primary coolant energy, Btu
V = net free containment volume, ft^3
t_P = time interval to end of blowdown, sec.

(ii) During the long-term post-blowdown phase of the accident characterized by low turbulence in the containment atmosphere, assume condensing heat transfer coefficients 1.2 times greater than those predicted by the Uchida data (Reference 3) and given in Table 3.

(iii) During the transition phase of the accident between the end of blowdown and the long-term post-blowdown phase, a reasonably conservative exponential transition in the condensing heat transfer coefficient should be assumed (See Figure 2).

The calculated condensing heat transfer coefficients based on this method should be applied to all exposed passive heat sinks, both metal and concrete, and for both painted and unpainted surfaces.

Heat transfer between adjoining materials in passive heat sinks should be based on the assumption of no resistance to heat flow at the material interfaces. An example is the containment liner to concrete interface.

(iv) Variations from these guidelines may be acceptable if the overall ECCS performance evaluation model produces an acceptable peak calculated fuel cladding temperature.

III. <u>REFERENCES</u>

1. 10 CFR Part 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors," and 10 CFR Part 50, Appendix K, "ECCS Evaluation Models."

2. T. Tagami, "Interim Report on Safety Assessment and Facilities Establishment Project in Japan for Period Ending June 1965 (No. 1)," prepared for the National Reactor Testing Station, February 28, 1966 (unpublished work).

3. H. Uchida, A. Oyama, and Y. Toga, "Evaluation of Post-Incident Cooling Systems of Light-Water Power Reactors," Proc. Third International Conference on the Peaceful Uses of Atomic Energy, Volume 13, Session 3.9, United Nations, Geneva (1964).

TABLE 1 IDENTIFICATION OF CONTAINMENT HEAT SINKS

1. Containment Building (*e.g.*, liner plate and external concrete walls, floor, sump, and linear anchors).

2. Containment Internal Structures (*e.g.*, internal separation walls and floors, refueling pool and fuel transfer pit walls, and shielding walls).

3. Supports (*e.g.*, reactor vessel, steam generator, pumps, tanks, major components, pipe supports, and storage racks).

4. Uninsulated Systems and Components (*e.g.*, cold water systems, heating, ventilation and air conditioning systems, pumps, motors, fan coolers, recombiners, and tanks).

5. Miscellaneous Equipment (*e.g.*, ladders, gratings, electrical cables, trays, and cranes).

TABLE 2 HEAT SINK THERMOPHYSICAL PROPERTIES

Material	Density kg/m^3 (lb/ft^3)	Specific Heat kJ/kg-°K(Btu/lb- °F)	Thermal Conductivity W/m-°K(Btu/hr-ft- °F)
Concrete	2330 (145)	0.654 (0.156)	1.6 (0.92)
Steel	7850 (490)	0.503 (0.12)	47 (27.0)

TABLE 3 UCHIDA HEAT TRANSFER COEFFICIENTS

Mass Ratio kg (lb) air / kg (lb) steam	Heat Transfer Coefficient W/m^2-°K (Btu/hr-ft^2- °F)	Mass Ratio kg(lb) air / kg(lb) steam)	Heat Transfer Coefficient W/m^2-°K (Btu/hr-ft^2- °F)
50	12 (2)	3	165 (29)
20	46 (8)	2.3	211 (37)
18	52 (9)	1.8	262 (46)
14	57 (10)	1.3	358 (63)
10	80 (14)	0.8	557 (98)
7	97 (17)	0.5	795 (140)
5	120 (21)	0.1	1590 (280)
4	137 (24)		

Figure 1
Area of Steel Heat Sinks Inside Containment

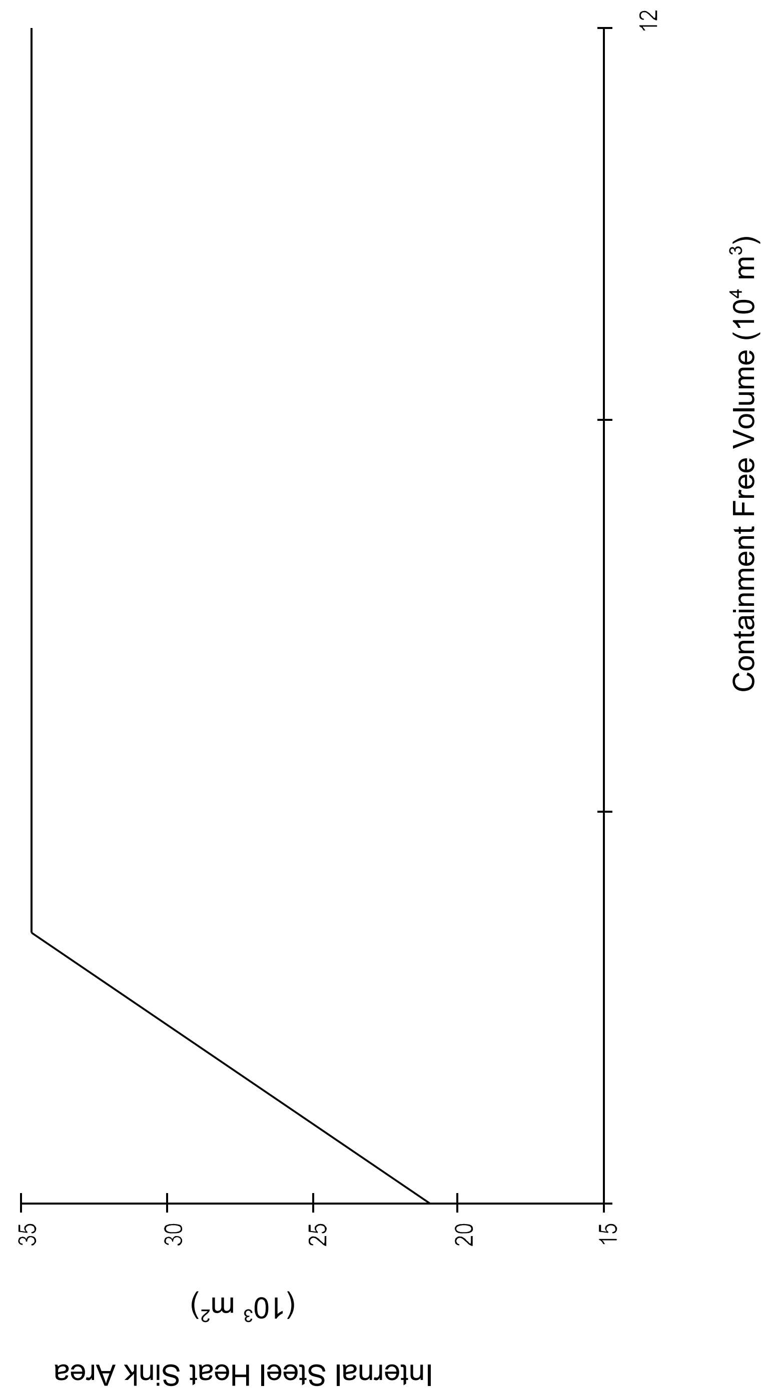

Figure 2
Condensing Heat Transfer Coefficients for Static Heat Sinks