U.S. NUCLEAR REGULATORY COMMISSION

# STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

## 6.2.5 COMBUSTIBLE GAS CONTROL IN CONTAINMENT

REVIEW RESPONSIBILITIES

Primary - Organization responsible for review of containment integrity

Secondary - None

## I. AREAS OF REVIEW

10 CFR 50.44, "Combustible Gas Control for Nuclear Power Reactors," is applicable to all power reactors. Proposed Regulatory Guide (RG) 1.7, Revision 3, "Control of Combustible Gas Concentrations in Containment" (Reference 1), describes methods that are acceptable to the NRC staff for implementing 10 CFR 50.44.

Note: This standard review plan (SRP) is primarily intended to cover new water-cooled reactor plant applications with characteristics (e.g., type and quantity of cladding materials) such that the potential for production of combustible gases is comparable to light water reactor designs licensed as of October 16, 2003 (the effective date of a major revision of 10 CFR 50.44). Guidance for a plant which had already received its operating license as of October 16, 2003, or for non-water-cooled reactor plants or water-cooled reactor plants that do not fall within the description above, may be found in proposed RG 1.7, Revision 3.

This section covers the information presented in the applicant's safety analysis report (SAR) or design control document (DCD) concerning the control of combustible gases in the containment

following a beyond-design-basis accident involving 100 percent fuel clad-coolant reaction or postulated accident to ensure conformance with the requirements of General Design Criteria (GDC) 5, 41, 42, and 43, and 10 CFR 50.44. Following an accident, hydrogen and oxygen may accumulate inside the containment.

After an accident, combustible gas is predominantly generated within the containment as a result of:

(a) Fuel clad-coolant reaction between the fuel cladding and the reactor coolant.
(b) Molten core-concrete interaction in a severe core melt sequence with a failed reactor vessel.

If a sufficient amount of combustible gas is generated, it may react with the oxygen present in the containment at a rate rapid enough to breach the containment or cause a leakage rate in excess of Technical Specification limits. Additionally, the associated pressure and temperature increase could damage systems and components essential to continued control of the post-accident conditions.

The review includes the following general areas:

1. The production and accumulation of combustible gases within the containment following a beyond-design-basis accident.

2. The capability to mix the combustible gases with the containment atmosphere and prevent high concentrations of combustible gases in local areas.

3. The capability to monitor combustible gas concentrations within containment, and, for inerted containments, oxygen concentrations within containment.

4. The capability to reduce combustible gas concentrations within containment by suitable means, such as igniters.

The review specifically covers the following analyses and aspects of combustible gas control system designs:

1. Analysis of combustible gas (e.g., hydrogen, carbon monoxide, oxygen) production and accumulation within the containment following a beyond-design-basis accident.

2. Analysis of the functional capability of the systems or passive design features provided to mix the combustible gas within the containment.

3. Analysis of the functional capability of the systems provided to reduce combustible gas concentrations within the containment.

4. Analyses of the capability of systems or system components to withstand dynamic effects, such as transient differential pressures that would occur early in the blowdown phase of an accident.

5. Analyses of the consequences of single active component malfunctions, to meet GDC 41.

6. The quality classification of each system.

7. The seismic design classification of each system.

8. The results of qualification tests performed on system components to demonstrate functional capability.

9. The design provisions and proposed program (including Technical Specifications at the operating license (OL) or combined license (COL) stage of review) for periodic inservice inspection, operability testing, and leakage rate testing of each system or component.

10. The functional aspects of instrumentation provided to monitor system or system component performance.

At the construction permit (CP) stage of review, the design of the systems provided for monitoring and controlling combustible gases within the containment may not be completely determined. In such cases, staff reviews the applicant's preliminary designs and statements of intent to comply with the acceptance criteria for such systems. At the OL stage, staff reviews the final designs of these systems to verify that they meet the acceptance criteria detailed in subsection II of this SRP section.

For design certification (DC) and COL applications, staff reviews the applicant's final safety analysis report to comply with the acceptance criteria for such systems.

For design certification and combined license (COL) reviews, the applicant's proposed information on the ITAAC associated with the systems, structures, and components (SSCs) related to this 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.

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 may contain requirements and restrictions that must be satisfied by the date of issuance of the combined license. 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. The review of seismic design and quality group classifications is performed under SRP Section 3.2.1 and SRP Section 3.2.2, respectively.

2. The actuation and control features of active components, including the hydrogen and oxygen monitors is reviewed under SRP Section 7.5.

3. The qualification test program for electrical valve operators, fans, hydrogen/oxygen sampling or analyzing equipment, igniters, and sensing and actuation instrumentation of the plant protection system, located both inside and outside the reactor containment is reviewed under SRP Section 3.11.

4. Proposed Technical Specifications pertaining to the operability and leakage rate testing of systems and components is reviewed under SRP Section 16.

5. Accessibility of combustible gas control systems equipment under postulated accident conditions is reviewed under SRP Section 12.3.

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

II. ACCEPTANCE CRITERIA

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

F. 10 CFR Part 50, § 50.44, as it relates to BWR and PWR plants being designed to: accommodate hydrogen generation equivalent to a 100 percent fuel clad-coolant reaction; limit containment hydrogen concentration to no greater than 10 percent; have a capability for ensuring a mixed atmosphere during design bases and significant beyond-design-bases accidents (a significant beyond-design-basis accident is an accident comparable to a degraded core accident at an operating (as of October 16, 2003) light-water reactor in which a metal-water reaction occurs involving 100 percent of the fuel cladding surrounding the active fuel region (excluding the cladding surrounding the plenum volume)); and provide containment-wide hydrogen control (such as igniters or inerting), if necessary, for certain severe accidents. Post-accident conditions should be such that an uncontrolled hydrogen/oxygen recombination would not take place in the containment, or the plant should withstand the consequences of uncontrolled hydrogen/oxygen recombination without loss of safety function or containment structural integrity.

G. GDC 5 as it relates to providing assurance that sharing of structures, systems, and components important to safety among nuclear power units will not significantly impair their ability to perform their safety functions.

H. GDC 41 as it relates to systems being provided to control the concentration of hydrogen or oxygen that may be released into the reactor containment following postulated accidents to ensure that containment integrity is maintained; systems being designed to suitable requirements, i.e., that there be suitable redundancy in components and features, and suitable interconnections to ensure that for either a loss of onsite or a loss

of offsite power the system safety function can be accomplished, assuming a single failure; and systems being provided with suitable leak detection, isolation, and containment capability to ensure that system safety function can be accomplished.

I. GDC 42 as it relates to the design of the systems to permit appropriate periodic inspection of components to ensure the integrity and capability of the systems.

J. GDC 43 as it relates to the systems being designed to permit periodic testing to ensure system integrity, and the operability of the systems and active components.

K. 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.

L. 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.

Specific criteria acceptable to meet[1] the requirements of 10 CFR Part 50, § 50.44, and GDC 5, 41, 42, and 43, are as follows:

6. In meeting the requirements of 10 CFR Part 50, § 50.44, and GDC 41 to provide systems to control the concentration of hydrogen in the containment atmosphere, materials within the containment that would yield hydrogen gas due to corrosion from the emergency cooling or containment spray solutions should be identified, and their use should be limited as much as practicable.

7. In meeting the requirements of 10 CFR Part 50, § 50.44, and GDC 41 to provide systems to control the concentration of hydrogen or oxygen in the containment atmosphere, the applicant should demonstrate by analysis, for non-inerted containments, that the design can safely accommodate hydrogen generated by an equivalent of a 100 percent fuel clad-coolant reaction, while limiting containment hydrogen concentration, with the hydrogen uniformly distributed, to less than 10 percent (by volume), and while maintaining containment structural integrity.

8. In meeting the requirements of 10 CFR Part 50, § 50.44(c)(3), regarding equipment survivability, equipment necessary for achieving and maintaining safe shutdown of the plant and maintaining containment structural integrity should perform its safety function during and after being exposed to the environmental conditions attendant with the release of hydrogen generated by the equivalent of a 100 percent fuel clad-coolant reaction including the environmental conditions created by activation of the combustible gas control system.

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[1]Note: 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 an acceptable method of complying with the NRC regulations.

9. In meeting the requirements of 10 CFR Part 50, § 50.44, to provide the capability for ensuring a mixed atmosphere in the containment during design bases and significant beyond-design-bases accidents, and of GDC 41 to provide systems as necessary to ensure that containment integrity is maintained, this capability may be provided by an active, passive, or combination system. Active systems may consist of a fan, a fan cooler, or containment spray. For passive or combination systems that use convective mixing to mix the combustible gases, the containment internal structures should have design features which promote the free circulation of the atmosphere. For all containment types, an analysis of the effectiveness of the method used for providing a mixed atmosphere should be provided. This analysis is acceptable if it shows that combustible gases will not accumulate within a compartment or cubicle to form a combustible or detonable mixture that could cause loss of containment integrity.

   Atmosphere mixing systems prevent local accumulation of combustible or detonable gases which could threaten containment integrity or equipment operating in a local compartment. Active systems installed to mitigate this threat should be reliable, redundant, single-failure proof, able to be tested and inspected, and remain operable with a loss of onsite or offsite power.

10. In meeting the requirements of 10 CFR Part 50, § 50.44, and GDC 41 regarding the functional capability of the combustible gas control systems to ensure that containment integrity is maintained, the design should meet the provisions of proposed RG 1.7, Revision 3, Section C.1.

11. To satisfy the design requirements of GDC 41:

    a. Performance tests should be performed on system components, such as hydrogen igniters and combustible gas monitors. The tests should support the analyses of the functional capability of the equipment.

    b. Combustible gas control system designs should include instrumentation needed to monitor system or component performance under normal and accident conditions. The instrumentation should be capable of determining that a system is performing its intended function, or that a system train or component is malfunctioning and should be isolated. The instrumentation should have readout and alarm capability in the control room. The containment hydrogen and oxygen monitors should meet the provisions of proposed RG 1.7, Revision 3, Section C.2.

12. To satisfy the inspection and test requirements of GDC 41, 42, and 43, combustible gas control systems should be designed with provisions for periodic inservice inspection, operability testing, and leak rate testing of the systems or components.

13. In meeting the requirements of 10 CFR Part 50, § 50.44(c)(5), regarding containment structural integrity, an analysis must demonstrate containment structural integrity, using an analytical technique that is accepted by the NRC staff and including sufficient supporting justification to show that the technique describes the containment response to the structural loads involved. The analysis must address an accident that releases

hydrogen generated from 100 percent fuel clad-coolant reaction accompanied by combustible gas burning. Systems necessary to ensure containment integrity must also demonstrate the capability to perform their functions under these conditions. One acceptable analytical technique is a demonstration that specific criteria of the ASME Boiler and Pressure Vessel Code, described in proposed RG 1.7, Revision 3, Section C.5, are met.

14. In meeting the requirements of 10 CFR Part 50, § 50.44(c), and GDC 41 for the design and functional capability of the combustible gas control systems, preliminary system designs and statements of intent in the SAR are acceptable at the CP stage of review if the guidelines of proposed RG 1.7, Revision 3, are endorsed.

## III. REVIEW PROCEDURES

The procedures described below provide guidance for the detailed review of the combustible gas control systems. The reviewer selects and emphasizes material from this SRP section, as may be appropriate for a particular case. Portions of the review may be done on a generic basis for aspects of combustible gas control systems design common to a class of plants or by adopting the results of previous reviews of similar plants.

Upon request from the primary reviewer, other review branches will provide input for the areas of review stated in subsection I, above. The primary reviewer obtains and uses such input as required to ensure that this review procedure is complete.

The combustible gas control systems include systems for mixing the combustible gases, monitoring combustible gas concentrations, and reducing the combustible gas concentrations. In general, all of the combustible gas control systems should meet the SRP acceptance criteria outlined in subsection II. 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. The system description and schematic drawings presented in the SAR should be sufficiently detailed to permit judgments to be made regarding system acceptability.

1. The reviewer determines that all potential, active mechanical failures and passive electrical failures have been identified and that no single failure would incapacitate an entire system.

2. The reviewer compares the quality standards applied to the systems to the provisions of proposed RG 1.7, Revision 3.

3. The reviewer compares the seismic design classifications of the systems to the provisions of proposed RG 1.7, Revision 3.

4. The reviewer reviews the qualification testing of systems and components, to establish the functional capability of the equipment.

5. The reviewer reviews the provisions made in the design of the systems and the program for periodic inservice inspection and operability testing of the systems or components. The inspections are reviewed with regard to the purpose of each inspection. The

operability tests that will be conducted are reviewed with regard to what each test is intended to accomplish. Judgment and experience from previous reviews are used to determine the acceptability of the inspection and test program.

6. The reveiwer reviews the proposed technical specifications, for plants at the OL or COL stage of review, for the systems used to control and monitor combustible gas and oxygen concentrations in the containment to ensure that the requirements of 10 CFR 50.44 and GDC 5, 41, 42, and 43 are met.

7. The reviewer reviews the capability to monitor system performance and control active components to be sure that control can be exercised over a system and that a malfunctioning system train or component can be isolated. The instrumentation provided for this purpose should be redundant and should enable the operator to identify the malfunctioning system train or component.

8. The reviewer reviews analyses of the functional capability of the systems, or passive design features, provided to mix combustible gases within the containment. The reviewer reviews the supporting information in the safety analysis report which should include elevation drawings of the containment showing the routing of ductwork and the circulation patterns caused by fans, sprays, or thermal convection. Special attention is paid to interior compartments to ensure that combustible gases cannot collect in them without mixing with the bulk containment atmosphere. The reviewer ensures that interior compartments are identified in the SAR and the provisions made to ensure circulation within them are discussed.

   Systems provided to mix the combustible gases within the containment may also be used for containment heat removal, e.g., the fan cooler and spray systems. The acceptability of the design of these systems is considered in the review of the containment heat removal systems in SRP Section 6.2.2.

9. The reviewer reviews the manner in which the systems provided to reduce combustible gas concentrations will be operated. The point at which the system is actuated (the control point) will be determined from the safety analysis report. For deliberate ignition systems, the control point is typically core exit temperature exceeding 1200 degrees Fahrenheit.

10. For reviews of design certification 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 design certification 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 design certification, an ESP 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 sufficient information has been provided and that his evaluation supports conclusions of the following type, to be included in the staff's safety evaluation report:

The staff concludes that the design and expected performance of the combustible gas control systems are acceptable and meet the requirements of 10 CFR Part 50, § 50.44, and GDC 5, 41, 42, and 43. This conclusion is based on the following:

1. The applicant has met the requirements of (cite regulation) with respect to (state limits of review in relation to regulation) by (for each item that is applicable to the review, state how it was met and why acceptable with respect to the regulation being discussed):

    a. meeting the regulatory positions in Regulatory Guide(s) _____;

    b. providing and meeting an alternative method to regulatory positions in Regulatory Guide _____, that the staff has reviewed and found to be acceptable;

    c. meeting the regulatory position in BTP ___;

    d. using calculational methods for (state what was evaluated) that have been previously reviewed by the staff and found acceptable; the staff has reviewed the impact parameters in this case and found them to be suitably conservative or performed independent calculations to verify acceptability of their analysis; and/or

    e. meeting the provisions of (industry standard number and title) that have been reviewed by the staff and determined to be appropriate for this application.

2. Repeat discussion for each regulation cited above.

For design certification and combined license reviews, the findings will also summarize (to the extent that the review is not discussed in other safety evaluation report sections) the staff's evaluation of the ITAAC, including design acceptance criteria (DAC), 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 design certifications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 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 superceded by a later revision.

## VI. REFERENCES

1. Proposed Regulatory Guide 1.7, Revision 3, "Control of Combustible Gas Concentrations in Containment."

2. Secy-03-0127, "Final Rulemaking—Risk-Informed 10 CFR 50.44, "Combustible Gas Control in Containment," dated July 24, 2003.

3. SECY-00-0198, "Status Report on Study of Risk-informed Changes to The Technical Requirements of 10 CFR Part 50 (Option 3) And Recommendations on Risk-informed Changes to 10 CFR 50.44 (Combustible Gas Control)," dated September 14, 2000.

4. SECY-93-087, "Policy, Technical, And Licensing Issues Pertaining to Evolutionary And Advanced Light-water Reactor (ALWR) Designs," dated April 2, 1993.

5. Regulatory Guide 1.155, Revision 0, "Station Blackout," August 1988.

6. NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the System 80+ Design, Docket No. 52-002," July 1994.

7. NUREG-1462, "Final Safety Evaluation Report Related to the Certification of the Advance Boiling Reactor Design," August 1994.

8. NUREG-1512, "Final Safety Evaluation Report Related to the Certification of the AP600 Standard Design, Docket No. 52-003," September 1998.

9. NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design, Docket No. 52-006," September 2004.

10. Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident."

11. 10 CFR Part 50, § 50.44, "Combustible Gas Control for Nuclear Power Reactors."

12. 10 CFR Part 50, § 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Cooled Reactors."

13. 10 CFR Part 50, § 50.46a, "Acceptance Criteria for Reactor Coolant System Venting Systems."

14. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems and Components."

15. 10 CFR Part 50, Appendix A, General Design Criterion 41, "Containment Atmosphere Cleanup."

16. 10 CFR Part 50, Appendix A, General Design Criterion 42, "Inspection of Containment Atmosphere Cleanup System."

17. 10 CFR Part 50, Appendix A, General Design Criterion 43, "Testing of Containment Atmosphere Cleanup System."

18. Branch Technical Position ASB 9-2, “Residual Decay Energy for Light Water Reactors for Long-Term Cooling,” attached to SRP Section 9.2.5.

19. NUREG/CR-4905, “Detonability of H-Air-Diluent Mixtures,” Sandia National Laboratory, June 1987.

20. NUREG/CR-4961, “A Summary of Hydrogen-Air Detonation Experiments,” Sandia National Laboratory, June 1987.

21. NUREG/CR-5275, “Flame Facility” (The Effect of Obstacles and Transverse Venting on Flame Acceleration and Transition to Detonation of Hydrogen-Air Mixtures at Large Scale), Sandia National Laboratory, April 1989.

22. NUREG/CR-5525, “Hydrogen-Air-Diluent Detonation Study of Nuclear Reactor Safety Analyses,” Sandia National Laboratory, December 1990.

## PAPERWORK REDUCTION ACT STATEMENT

The information collections contained in the draft Standard Review Plan are covered by the requirements of 10 CFR Part 50 and 52, which were approved by the Office of Management and Budget, approval number 3150-0011 and 3150-0151.

## Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid OMB control number.

**SRP Section 6.2.5**
Description of Changes

Revision 3 to this SRP section is based on Secy-03-0127, “Final Rulemaking—Risk-Informed 10 CFR 50.44, “Combustible Gas Control in Containment,” Attachment 6, “Standard Review Plan - NUREG-0800 in Conjunction with Risk-Informed Revision to 50.44, Section 6.2.5, Combustible Gas Control in Containment,” and Attachment 5, “Regulatory Guide 1.7, “Control of Combustible Gas Concentrations in Containment,” See ML031670912. The Commission approved the revision to 10 CRF 50.44, in Staff Requirements Memorandum dated August 28, 2003.

In addition, the Revision 3 was administratively updated in accordance with NRR Office Instruction, LIC 200, Standard Review Plan (SRP) Process.