NUREG-75/087

U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 6.2.5 COMBUSTIBLE GAS CONTROL IN CONTAINMENT

REVIEW RESPONSIBILITIES

Primary - Containment Systems Branch (CSB)

Secondary - Accident Analysis Branch (AAB)

I. AREAS OF REVIEW

CSB reviews the information presented in the applicant's safety analysis report (SAR) concerning the control of combustible gases in the containment following a loss-of-coolant accident. Following a loss-of-coolant accident, hydrogen and oxygen may accumulate inside the containment. The major sources of hydrogen and oxygen are: a chemical reaction between the fuel rod cladding and steam, the corrosion of aluminium and other materials by an alkaline spray solution, and the radiolytic decomposition of the water in the reactor core and the containment sump. If excessive hydrogen is generated, it may combine with oxygen in the containment atmosphere. For inerted containments, the potential exists for hydrogen to combine with oxygen generated following the accident. The CSB review includes the following general areas:

1. The production and accumulation of combustible gases within the containment following a postulated loss-of-coolant 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.
4. The capability to reduce combustible gas concentrations within containment by suitable means, such as recombination, dilution, or purging.

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

1. An analysis of combustible gas (i. e., hydrogen and oxygen) production and accumulation within the containment following a loss-of-coolant accident.

2 An analysis of the functional capability of the systems provided to mix the combustible gas within the containment.

3. An 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 a loss-of-coolant accident.

5. Analyses of the consequences of single active component malfunctions in each system.

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 and operability in the accident environment.

9. The design provisions and proposed program (including technical specifications at the operating license stage of review) for periodic inservice inspection and operability testing of each system or component.

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

11. The extent of sharing of system components between sites or between units at a multi-unit site.

AAB is responsible for determining, from a radiological dose standpoint, the acceptability of purge systems provided to control combustible gas concentrations within the containment following a loss-of-coolant accident. In order to compute the purge doses, AAB will need the elapsed time (in days) following a loss-of-coolant accident before purge system operation becomes necessary and the purge rate (in scfm). CSB provides AAB with this information.

At the construction permit (CP) stage of review, the design of the systems provided for monitoring and reducing the concentrations of combustible gases within the containment may not be completely determined. In such cases, CSB reviews the applicant's preliminary designs and statements of intent to comply with the acceptance criteria for such systems. At the operating license (OL) stage, CSB reviews the final designs of these systems to verify that they meet the acceptance criteria detailed below.

II. ACCEPTANCE CRITERIA

1. The analysis of hydrogen and oxygen production in the containment following postulated accidents, for the purpose of establishing the design basis for combustible gas control systems, should be based on the parameters listed in Table 1 of Branch Technical Position CSB 6-2. Branch Technical Position (BTP) CSB 6-2 is an acceptable interim alternative to Regulatory Guide 1.7, pending completion of the rulemaking proceeding on inerting ordered by the Commission in connection with the Vermont Yankee matter, Docket No. 50-271, Memorandum and Order, November 7, 1974, and subsequent revision of Regulatory Guide 1.7. BTP CSB 6-2 supplements and amends Regulatory Guide 1.7 as necessary to take account of the progress in engineered safety feature designs and standards since the guide was written and various features of recent containment designs.

2. The fission product decay energy used in the calculation of hydrogen and oxygen production from radiolysis of the emergency core cooling water and sump water is acceptable if it is equal to or more conservative than the decay energy model given in Branch Technical Position APCSB 9-2 in Standard Review Plan 9.2.5.

3. A system should be provided to mix the combustible gases within the containment. The functional design of this system will depend on the type of containment. This system may consist of a fan, a fan cooler, or containment spray. An analysis should be presented which shows that excessive stratification of combustible gases will not occur within the containment or within a containment subcompartment. For containments which rely on convective mixing in conjunction with system operation to mix the combustible gases, the containment internal structures must have design features which promote the free circulation of the atmosphere. An analysis of the effectiveness of these features for convective mixing should be presented. This analysis is acceptable if it can be shown that combustible gases will not accumulate within a compartment or cubicle to form an explosive mixture.

4. The systems provided to reduce the concentration of hydrogen or oxygen in the containment will be accepted, from a functional standpoint, if analyses indicate that a single system train is capable of maintaining the concentration of hydrogen or oxygen below the concentration limits specified in Table 1 of BTP CSB 6-2. Acceptance of the functional capability of the systems is based on confirmatory analyses performed by CSB using system operating parameters presented in the safety analysis report. The proposed operation of the combustible gas control equipment, excluding containment atmosphere dilution (CAD) systems, is acceptable if there is an approprate margin, e.g., on the order of 0.5 v/o, between the limiting hydrogen concentration limit and the hydrogen concentration at which the equipment would be actuated. The proposed operation of CAD systems will be acceptable if there is a margin of 1 v/o between the limiting hydrogen or oxygen concentration limit, depending on which gas being controlled, and the concentration at which the system would be actuated. This additional margin is needed to allow time for the CAD system to become operational. Repressurization of the containment should be limited to less than 50% of the containment design pressure.

Under loss-of-coolant accident conditions, system components such as ductwork and equipment housings, e.g., for fans, fan-coolers, filters, and recombiners, would be subjected to external transient differential pressures and internal pressure surges. These components should be capable of withstanding all related environmental conditions imposed on them, including steam-laden atmosphere differential pressures and pressure surges, without loss of function. A description of the design provisions, such as pressure relief devices or conservative structural design, supporting analyses, and results of tests should be provided to support the conservatism of design.

5. Combustible gas control systems should meet the redundancy and power source requirements for engineered safety features and should be designed to withstand a single active component failure. Supporting failure mode and effects analyses of each system should be provided in the safety analysis report.

6. Combustible gas control systems should be designed, fabricated, erected, and tested to Group B quality standards, as recommended in Regulatory Guide 1.26.

7. Combustible gas control systems, including foundations and supports, should be designated as seismic Category I, i.e., designed to withstand the effects of the safe shutdown earthquake without loss of function, as recommended in Regulatory Guide 1.29.

8. Qualification tests should be performed on system components, such as hydrogen recombiners, combustible gas analyzers, air moving equipment motors, and valve operators. The tests should support the analyses of the functional capability of the equipment and demonstrate that the equipment will remain operable in the accident environment for as long as accident conditions require.

9. Combustible gas control systems should be designed with provisions for periodic inservice inspection and operability testing of the systems or components. The inspection and test program is acceptable if it is judged to be consistent with that proposed for other engineered safety features.

10. 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.

11. The sharing of system equipment between nuclear power units at a multi-unit site or between sites is acceptable provided (a) the availibility of the shared equipment meets the redundancy requirements for an engineered safety feature, (b) the shared equipment is designed to seismic Category I criteria, (c) the shared equipment is mounted in a seismic Category I structure, and (d) adequate design, installation, and procedural provisions have been made.

12. BTP CSB 6-2 recommends that a backup purge system be provided. The backup purge system is not required to be designed to engineered safety feature requirements with regard to single failure protection since it is not the primary method for controlling combustible gas concentrations in the containment. The backup purge system is acceptable if purge doses are within the guidelines established in BTP CSB 6-2.

13. If the designs of the combustible gas control systems have not been completed at the construction permit stage of review, they will be acceptable if the preliminary system designs and statements of intent in the SAR conform to BTP CSB 6-2.

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 plan, 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.

1. CSB reviews the applicant's analyses of the production and accumulation of oxygen and hydrogen in the containment following postulated loss-of-coolant accidents, to see that the recommendations and guidelines of BTP CSB 6-2 have been followed. With regard to the extent of metal-water reaction to be considered, the combustible gas control system designs of some boiling water reactor plants with BWR6/Mark III containments have been evaluated and accepted on the basis of an assumed metal-water reaction involving one percent of the cladding mass. Since this assumption is conservative with respect to BTP CSB 6-2 (the BTP would indicate about 0.7% reaction of the cladding mass in these cases), it will continue to be an acceptable basis for these plants, at the option of the applicants. As necessary, the CSB will make confirmatory analyses of combustible gas production and accumulation. These analyses are done using the COGAP computer code, a description of which is attached as Appendix A to this plan. The safety analysis report should contain the required code input data. The purposes of the analyses are:

   a. To confirm the predictions of hydrogen and oxygen generation appearing in the safety analysis report.
   b. To verify that the systems provided for combustible gas control are capable of maintaining the concentrations of hydrogen and oxygen below the concentration limits specified in Table 1 of BTP CSB 6-2.
   c. To confirm the elapsed time before purge system operation becomes necessary.
   d. To confirm that the assumed purge rate will maintain combustible gas concentrations within acceptable limits.

   The above analyses should be done early in the plant review, since this information is needed by AAB to perform the purge dose computations upon which the acceptability of the purge system is based.

2. 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 design requirements for engineered safety features, as outlined in Section II. The system description and schematic drawings presented in the safety analysis report should be sufficiently detailed to permit judgments to be made regarding system acceptability.

   CSB determines that all potential, single active mechanical failures and passive electrical failures have been identified and that no single failure would incapacitate the entire system. Passive mechanical failures, beyond those possible from missile impact, need not be considered in view of the design and construction standards for the systems.

   CSB compares the quality standards applied to the systems to Regulatory Guide 1.26.

   CSB compares the seismic design classifications of the systems to Regulatory Guide 1.29.

3. CSB reviews the environmental conditions and duration of tests used for the qualification of system components. CSB determines whether the test conditions and duration are representative of post-accident conditions to which the equipment may be subjected. CSB will ascertain that the equipment can operate in the accident environment for as long as accident conditions require.

4. CSB 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.

   For plants at the operating license stage of review, CSB reviews the proposed technical specifications for the systems used to control combustible gas concentrations in the containment to assure that the intent of General Design Criteria 41, 42,and 43 are met.

5. CSB 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.

6. CSB reviews the extent of sharing of system equipment between plants at multi-unit sites or between sites to assure that system redundancy requirements are satisfied and that adequate procedural provisions have been made to assure the availability of the shared equipment on a timely basis. The results of CSB analyses of combustible gas production and accumulation are used to confirm the time available following postulated loss-of-coolant accidents to transport the shared equipment to the plant and put it into operation.

7. CSB reviews analyses of the functional capability of the systems provided to mix combustible gases within the containment. CSB 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 assure that combustible gases cannot collect in them without mixing with the bulk containment atmosphere. CSB ensures that interior compartments are identified in the safety analysis report and the provisions made to assure 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 Standard Review Plan 6.2.2.

8. CSB reviews the manner in which the systems provided to reduce combustible gas concentrations will be operated. The concentration at which the system is actuated (the control point) will be determined from the safety analysis report. The margin between the control point and the hydrogen or oxygen concentration limits specified in Table 1 of BTP CSB 6-2 is checked. CSB determines whether the uncertainty in measuring combustible gas concentrations and the time lag in making the system operational after reaching the control point have been covered by the minimum allowable margin specified in the acceptance criteria.

9. At the construction permit stage of review, the design of the combustible gas control systems may not be complete. In such cases, CSB reviews the preliminary design information and the design criteria that have been established.

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 scope of review of the design and functional capability of the combustible gas control systems for the ______________ plant has included drawings and descriptive information of the equipment to mix the containment atmosphere, monitor combustible gas concentrations, and reduce combustible gas concentrations within the containment following the design basis accident. The review has also included the applicant's proposed design bases for the combustible gas control systems, and the analyses of the functional capability of the systems provided to support the adequacy of the design bases.

"The basis for the staff's acceptance has been the conformance of system designs and design bases to the Commission's regulations as set forth in the general design criteria, and to applicable regulatory guides, branch technical positions, and industry codes and standards. (Special problems or exceptions that the staff takes to the design or functional capability of the combustible gas control systems should be discussed.)

"The staff concludes that the design of the combustible gas control systems conforms to all applicable regulations, guides, staff positions, and industry standards, and is acceptable."

V. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 41, "Containment Atmosphere Cleanup."

2. 10 CFR Part 50, Appendix A, General Design Criterion 42, "Inspection of Containment Cleanup System."

3. 10 CFR Part 50, Appendix A, General Design Criterion 43, "Testing of Containment Atmosphere Cleanup System."

4. 10 CFR Part 50, Appendix A, General Design Criterion 50, "Containment Design Basis."

5. Regulatory Guide 1.7, "Control of Combustible Gas Concentrations in Containment Following a Loss-of-Coolant Accident," and the Supplement to Regulatory Guide 1.7.

6. Regulatory Guide 1.26, "Quality Group Classifications and Standards."

7. Regulatory Guide 1.29, "Seismic Design Classification."

8. L. Baker, Jr., and L. C. Just, "Studies of Metal-Water Reaction at High Temperature, III Experimental and Theoretical Studies of the Zirconium-Water Reaction," ANL-6548, Argonne National Laboratory, May 1962.

9. J. J. DiNunno, F. D. Anderson, R. E. Baker, and R. L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, USAEC, March 23, 1962.

10. H. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors," Bulletin 503, Bureau of Mines (1952).

11. A. O. Allen, "The Radiation Chemistry of Water and Aqueous Solutions," Van Nostrand Co., New York (1961).

12. Branch Technical Position APCSB 9-2, "Residual Decay Energy for Light Water Reactors for Long-Term Cooling," attached to Standard Review Plan 9.2.5.

13. Branch Technical Position CSB 6-2, "Control of Combustible Gas Concentrations In Containment Following a Loss of Coolant Accident," attached to this plan.

APPENDIX A
STANDARD REVIEW PLAN 6.2.5
DESCRIPTION OF COGAP

INTRODUCTION

A digital computer program, COGAP (Combustible Gas Analyzer Program), has been developed by the Containment Systems Branch to provide in-house capability for determining hydrogen-oxygen concentrations within reactor containments following loss-of-coolant accidents. The program can also evaluate the performance of a number of combustible control systems. They are the containment atmosphere dilution system (CAD), the recombiner system, and the backup purge system.

DISCUSSION

In the event of a loss-of-coolant accident (LOCA), hydrogen and oxygen gases will be generated within the reactor containment by several reactions. They are:

1. Metal-water reaction involving the zirconium fuel cladding and the reactor coolant, producing free hydrogen.

2. Radiolytic decomposition of the post-accident emergency cooling solutions, producing both oxygen and hydrogen.

3. Aluminum corrosion by water solutions, producing hydrogen.

4. Zirc corrosion by water solutions, producing hydrogen.

If a sufficient amount of hydrogen is generated, it may react with the O_2 present in the containment atmosphere or, in the case of inerted containments, with the oxygen generated following a LOCA.

The extent of zirc-water reaction and associated hydrogen production depends strongly on the course of events assumed for the accident. Analytically the reaction can be described by:

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$$

$$1 \text{ lb } Zr \rightarrow 0.043956 \text{ lb } H_2$$

$$1 \text{ lb } Zr \rightarrow 0.021978 \text{ lb-mole } H_2.$$

Therefore, one pound of reacted zirconium will produce 0.021978 pound-moles of free hydrogen. Assuming the perfect gas relationship, this is equivalent to 8.4866 scf/lb Zr:

$$V = \frac{MRT}{P}$$

$$V = \frac{0.021978(10.71)(530)}{14.7}$$

$$V = 8.4866 \text{ scf/lb Zr.}$$

The total amount of hydrogen produced is based on the amount of reacted zirconium, as determined by the assumptions given in Branch Technical Position CSB 6-2. The computer program, to maintain a degree of generality, allows the reaction percentage to be specified as an input quantity. The expression used is:

$$WG = (.022)(WZR)(f_{MW})$$

where

WG = pound moles of hydrogen generated

WZr = weight of zirconium fuel element clad

f_{MW} = zirconium-water reaction fraction.

The rate of gas production from radiolysis depends upon the power decay profile and the amount of fission products released to the coolant. The radiolytic hydrogen production rate at time (t) is given by:

$$S_H(t) = \frac{P}{(B)\ (N)} \quad \frac{G_c E_c(t) + G_s E_s(t)}{100}$$

where

$S_H(t)$ = hydrogen production rate, lb-mole/sec

P = operating reactor power level, MWt

B = conversion factor, 454 gm-mole/lb-mole

N = Avogadro's number, 6.023×10^{23} molecules/gm-mole

G_c = radiolytic hydrogen yield in core, molecules/100 ev

$E_c(t)$ = gamma ray fission product energy absorbed by core coolant, ev/sec-MWt

G_s = radiolytic hydrogen yield in solution, $\frac{\text{molecules}}{\text{100 ev}}$

$E_s(t)$ = energy absorbed in coolant outside core due to fission products dissolved in coolant, ev/sec-MWt.

The quantity $E_c(t)$ is defined by:

$$E_c(t) = (f_\gamma)_c\ H_\gamma(t)$$

where

$(f_\gamma)_c$ = fraction of fission product gamma energy absorbed by coolant in core region

$H_\gamma(t)$ = gamma energy production rate, $\frac{\text{ev}}{\text{sec-MWt}}$.

Similarly, $E_s(t)$ is defined by:

$$E_s(t) = (f_{\gamma+\beta})_s \, H_{\gamma+\beta}(t) + f_I \, H_I(t)$$

where

$(f_{\gamma+\beta})_s$ = fraction of total solid fission product energy absorbed in coolant outside core

$H_{\gamma+\beta}(t)$ = total solid fission product energy production rate, ev/sec-MWt

f_I = fraction of iodine isotope energy absorbed in coolant outside core

$H_I(t)$ = iodine isotope energy production rate, ev/sec-MWt.

The equations for oxygen generation by radiolysis are identical to those above describing hydrogen evolution except that the yield is one half that of hydrogen. These equations have been incorporated into the COGAP program. For calculational purposes, the reactor decay profiles ($H_\gamma(t)$, $H_{\gamma+\beta}(t)$, and $H_I(t)$) specified by the ANS-5.1 draft standard for two-year reactor operation have been fitted by several finite exponential series expressions and also incorporated into the program. The resulting equations are:

$$H_\gamma(t) = 10^{22}(5.1912e^{-9.8 \times 10^{-5}t} + 0.8743e^{-6.5 \times 10^{-6}t}$$

$$+ 0.6557e^{-5.7 \times 10^{-7}t} + .4098e^{-7.4 \times 10^{-8}t} + .0150e^{-8.0 \times 10^{-10}t})$$

$$H_{\gamma+\beta}(t) = 2.0 \, H_\gamma(t)$$

$$H_I(t) = 10^{22}(0.8197e^{-6.1 \times 10^{-5}t} + .3279e^{-1.1 \times 10^{-5}t}$$

$$+ .0574e^{-1.0 \times 10^{-6}t})$$

where

t = time after reactor shutdown, sec.

Between 400 and 4×10^7 sec, the equations overpredict the standard curve by 20%. The equations underpredict the standard curve soon after shutdown. However, this does not seriously affect the results due to the short time period involved. The equations are equivalent to the afterheat decay curve in BTP APCSB 9-2 over the times of interest for post-accident hydrogen generation. It should also be noted that the COGAP formulation overpredicts the radiolytic hydrogen generation by a small amount due to a "double-counting" of the gamma energy of those fission products assumed to be released from the fuel rods.

Hydrogen generation due to aluminum corrosion is normally considered only when additives are used in the cooling solution. When applicable, gas production is governed by the following expression:

$$S_c(t) = \frac{A\rho BC(t)}{(12)(3.15 \times 10^7)}$$

where

$S_c(t)$ = hydrogen production rate, lb-mole/sec

A = surface area of aluminum, ft^2

ρ = aluminum density, lb/ft^3

B = lb-moles of hydrogen per lb of aluminum

C(t) = aluminum corrosion rate, in/year.

The aluminum corrosion rate has been described by an exponential fit in COGAP to account for an increased rate due to high temperatures early in the accident followed by a constant rate for the remaining period of the analysis.

The chemical relationship by which hydrogen is formed has been assumed to be:

$$2\ Al + 3\ H_2O \rightarrow 3\ H_2 + Al_2O_3$$

$$1\ lb\ Al \rightarrow 0.111\ lb\ H_2$$

$$1\ lb\ Al \rightarrow 0.0555\ lb\text{-}mole\ H_2$$

therefore

$$B = 0.0555\ lb\text{-}mole\ H_2/lb\ Al$$

Zinc corrosion has been treated in a similar fashion.

COGAP INPUT REQUIREMENTS

COGAP has been developed to minimize the required input information. All data associated with the power decay profile has been incorporated into the program and need not be entered. Basic input requires eight input cards per case. Multiple cases can be stacked back to back, allowing an unlimited number of cases to be run at any given time.

The following is a detailed description of the data required per case:

1st card: title card.

Information contained within the first 72 columns will be printed as a general output heading. It should be used to describe the power plant under consideration.

2nd card: control card (right justified)(integers)

		columns			
5	10	15	20	25	30
I1	IH1	J1	K1	ITEMP	ICASE

I1 = total number of time steps considered (must not be greater than 50)(equal to IH1 + J1 + K1 + 2)

IH1 = number of time steps in initial time step grid

J1 = number of time steps in second time step grid

K1 = number of time steps in third time step grid

ITEMP = number of temperature points to be read

ICASE = 0 if this is last case

= 1 if another case following.

3rd card: time step information (floating)

columns

12	24	36
DELTA	DELTB	DELTC

DELTA = constant time step for first time grid, days

DELTB = constant time step for second time grid, days

DELTC = constant time step for third time grid, days.

4th card: containment data (floating)

columns

12	24	36	48	60	72
POW	V(1)	V(2)	ZIRWGT	O	H

POW = reactor power level, MWt

V(1) = containment free volume, ft^3

V(2) = 2nd containment free volume (wetwell), ft^3

ZIRWGT = zirconium cladding weight, pounds

O = oxygen dissolved in primary, pound-moles

H = hydrogen dissolved in primary, pound-moles.

5th card: containment data (continued)

columns

12	24	36	48	60	72
P	T	OF	QREC	TIME	PURG

P = initial containment pressure, psia

T = initial containment temperature, rankine

OF = initial oxygen volume fraction (.209 std. air)

QREC = recombiner flow rate, cfm

(Must be zero if purging is to be considered)

TIME = time recombiner is started, days

(program will start recombiner at time nearest but less than specified time)

PURG = purging rate, cfm (must be zero if recombiner is to be used).

<u>6th card</u>: gas constants (floating)

columns

12	24	36	48	60	71
f_{mw}	A	G_c	G_s	$(f_\gamma)_c$	$(f_{\gamma+\beta})_s$

f_{mw} = zirc-water reaction fraction

A = aluminum surface area, ft^2

G_c = G-H_2, core solution, mole/100 ev

G_s = G-H_2, sump solution, mole/100 ev

$(f_\gamma)_c$ = fraction of gammas absorbed in coolant in core region

$(f_{\gamma+\beta})_s$ = fraction of solid fission product energy absorbed in solution outside core

<u>7th card</u>: gas constants (floating)

columns

12	24	36	48	60	72
f_I	BLANK	D	HF	TI	FLOW

f_I = fraction of iodine fission product energy absorbed in solution outside core

D = time constant $>9.0 \times 10^8$

HF = H_2 concentration fraction at which purging will begin

TI = time to initiate nitrogen addition, sec

FLOW = CAD nitrogen flow rate, scf/sec.

<u>8th card</u>: temperature profile

columns

12	24	36	48	60	72
T(1)	T(2)	T(3)			T(ITEMP)

T(1) = containment temperature, rankine (for first time increment)

T(2) = containment temperature, rankine (for second time increment)

T(ITEMP) = containment temperature, rankine (for ITEMP time increment)

BRANCH TECHNICAL POSITION CSB 6-2

CONTROL OF COMBUSTIBLE GAS CONCENTRATIONS IN CONTAINMENT FOLLOWING A LOSS-OF-COOLANT ACCIDENT*

A. BACKGROUND

General Design Criterion 41 requires that systems to be provided as necessary to control the concentrations of hydrogen, oxygen, and other substances which may be released into the reactor containment following postulated accidents, to assure that containment integrity is maintained. General Design Criterion 50 requires, in part, that containment be designed to accommodate with margin "metal-water and other chemical reactions that may result from degraded emergency core cooling functioning." This branch technical position (BTP) describes an acceptable method of implementing these criteria for light water reactor plants with cylindrical, zircaloy-clad, oxide fuel. Evaluations of other light water reactor fuels, with stainless steel cladding or with non-cylindrical cladding, will continue to be made on an individual case basis.

Following a loss-of-coolant accident (LOCA), hydrogen gas may accumulate within the containment as a result of:

1. Metal-water reaction involving the zirconium fuel cladding and the reactor coolant.

2. Radiolytic decomposition of the post-accident emergency cooling solutions (oxygen will also evolve in this process).

3. Corrosion of metals by solutions used for emergency cooling or containment spray.

If a sufficient amount of hydrogen is generated, it may react with the oxygen present in the containment atmosphere or, in the case of inerted containments, with the oxygen generated following the accident. The reaction would take place at rates rapid enough to lead to high temperatures and significant overpressurization of the containment, which could result in a leakage rate above that specified in the limiting conditions for operation (technical specifications). Damage to systems and components essential to the continued control of post-LOCA conditions could also occur.

The extent of metal-water reaction and associated hydrogen production depends strongly on the course of events assumed for the accident and on the effectiveness of emergency cooling systems. Evaluations of the performance of emergency core cooling systems (ECCS) included as engineered safety features on current light water cooled reactor plants have been made by reactor designers using analytical models described in the Commission's Interim Policy Statement of 1971. These calculations are further discussed in the staff's Concluding Statement in the rulemaking hearings, Docket RM-50-1. The result of such evaluations is that for plants of current design, operated in conformance with the Interim Policy Statement, the calculated metal-water reaction

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* See Section II.1 of Standard Review Plan 6.2.5.

amounts to only a fraction of one percent of the fuel cladding mass. As a result of the rulemaking hearing (Docket RM-50-1), the Commission has recently adopted new regulations dealing with the effectiveness of ECCS (10 CFR §50.46).

The staff believes it appropriate to consider the experience obtained from the various ECCS-related analytical studies and test programs such as code developmental efforts, fuel densification, blowdown and core heat-up studies, and the PWR and BWR FLECHT tests, and to take account of the foregoing increased conservatism, for plants with ECCS evaluated under §50.46, in setting the amount of initial metal-water reaction to be assumed for the purpose of establishing design requirements for combustible gas control systems. The staff has always separated the design bases for ECCS and for containment systems, and has required containment systems such as the combustible gas control system to be designed to withstand a more degraded condition of the reactor than the ECCS design basis permits. The approach is consistent with provisions of General Design Criterion 50 where the need to provide margins to account for the effects of degraded ECCS function is noted. Although the level of degradation considered might lead to an assumed extent of metal-water reaction in excess of that calculated for acceptable ECCS performance, it does not lead to a situation involving a total failure of the ECCS. The staff feels that this "overlap" in protection requirements provides an appropriate and prudent safety margin against unpredicted events during the course of accidents.

Accordingly, the staff believes that the amount of hydrogen assumed to be generated by metal-water reaction in establishing combustible gas control system performance requirements should be based on the amount calculated in demonstrating compliance with §50.46, but that the amount of hydrogen required to be assumed should include a margin above that calculated. To obtain this margin, the assumed amount of hydrogen should be no less than five times that calculated in accordance with §50.46.

Since the amounts of hydrogen thus determined may be quite small for many plants, as a result of the other more stringent requirements for ECCS performance in the criteria of §50.46, it is consistent with the consideration of the potential for degraded ECCS performance discussed above to establish also a lower limit on the assumed amount of hydrogen generated by metal-water reactions in establishing combustible gas control system requirements. In establishing this lower limit, the staff has noted that the maximum metal-water reaction permitted by the ECCS performance criteria is one percent of the cladding mass.* In fact, the designs of several plants of the [illegible]6-Mark III type using one percent of the cladding mass as a combustible gas control system basis have recently been reviewed and accepted by the staff and the Advisory Committee on Reactor Safeguards. These plants were reviewed on an individual case basis, since they were the first of the design type. The general and continued use of this "one percent of the mass" value as a lower limit for assumed hydrogen production, however, would unnecessarily penalize reactors with thicker cladding, since for the same thermal conditions in the core in a postulated LOCA the thicker cladding would not, in fact, lead to increased hydrogen generation. This is because the hydrogen generation from metal-water reaction is a surface phenomenon. The staff considers that a more appropriate basis for setting the lower limit would be an amount of hydrogen assumed to be generated per unit cladding area. It is convenient to specify for

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*10 CFR Part 50, §50.46(b)(3) "The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react."

this purpose a hypothetical uniform depth of cladding surface reaction. The lower limit of metal-water reaction hydrogen to be assumed is then the hypothetical amount that would be generated if all metal to a specified depth in the outside surfaces of the cladding cylinders surrounding the fuel (excluding the cladding surrounding the plenum volume) were to react.

In selecting a specified depth to be assumed as a lower limit for all reactor designs, the staff has calculated the depth that could correspond to the "one percent of the mass" value for the current core design with the thinnest cladding. This depth (0.01 times the thickness of the thinnest fuel cladding in use) is 0.00023 inches.

In summary, the amount of hydrogen assumed to be generated by metal-water reaction in determining the performance requirements for combustible gas control systems should be five times the maximum amount calculated in accordance with §50.46, but no less than the amount that would result from reaction of all the metal in the outside surfaces of the cladding cylinders surrounding the fuel (excluding the cladding surrounding the plenum volume) to a depth of 0.00023 inches.

It should be noted that the extent of initial metal-water reaction calculated for the first core of a plant, and used as a design basis for the hydrogen control system, becomes a limiting condition for all reload cores in that plant unless the hydrogen control system is subsequently modified and reevaluated.

The staff believes that hydrogen control systems in plants receiving operating licenses on the basis of ECCS evaluations under the Interim Policy Statement should continue to be designed for the five percent initial metal-water reaction specified in the original edition of Safety Guide 7. As operating plants are reevaluated as to ECCS performance under 10 CFR §50.46, a change to the new hydrogen control basis enumerated above may be made by appropriate amendments to technical specifications. For plants receiving construction permits on the basis of ECCS evaluations under the Interm Policy Statement, the staff believes that a commitment by the applicant to a specified maximum metal-water reaction, as determined by the provisions of this BTP, is an acceptable alternate basis for the design of a hydrogen control system.

No assumption as to rate of evolution was associated with the magnitude of the assumed metal-water reaction originally given in Safety Guide 7. The metal-water reaction rate is of significance when establishing system performance requirements for containment designs that employ time-dependent hydrogen control features. The staff recognizes that it would be unrealistic to assume an instantaneous release of hydrogen from an assumed metal-water reaction. The staff believes that for the design of a hydrogen control system, it should be assumed that the initial metal-water reaction would occur over a short period of time early in the LOCA transient, i.e., near the end of the blowdown and core refill phases of the LOCA transient. Any hydrogen thus evolved would mix with steam and air and be rapidly distributed throughout the containment compartments enclosing the reactor primary coolant system by the steam flowing from the postulated pipe break. These compartments include the "drywell" in typical boiling water reactor containments, the "lower volume" of ice condenser containments, and the full volume of "dry" containments. The blowdown and refill phase duration is generally several minutes, and the staff believes that the assumption of a two-minute evolution time at a constant reaction rate, with the resulting hydrogen uniformly distributed in the containment compartments enclosing the primary coolant system, is appropriately conservative for the design of hydrogen control systems. The effects of steam within the containment and containment subcompartments should be considered in the evaluation of the mixture composition.

The rate of production of gases from radiolysis of coolant solutions depends on (1) the amount and quality of radiation energy absorbed in the specific coolant solutions employed and (2) the net yield of gases generated from the solutions due to the absorbed radiation energy. Factors such as coolant flow rates and turbulence, chemical additives in the coolant, impurities, and coolant temperature can all exert an influence on the gas yields from radiolysis. The hydrogen production rate from corrosion of materials within the containment, such as aluminum, depends on the corrosion rate which in turn depends on such factors as the coolant chemistry, the coolant pH, the metal and coolant temperatures, and the surface area exposed to attack by the coolant. Accurate values of these parameters are difficult to establish with certainty for the conditions expected to prevail following a loss-of-coolant accident.

The staff has reviewed the available information concerning these parameters, including the results of calculations and experiments. Table 1 defines values and other assumptions which the staff believes to be reasonably conservative that may be used for purposes of evaluating the production of combustible gases following a loss-of-coolant accident.

If these assumptions are used to calculate the concentration of hydrogen (and oxygen) within the containment structures of reactor plants following a loss-of-coolant accident, the hydrogen concentration is calculated to reach the flammable limit within periods of less than a day after the accident for the smallest containments and up to more than a month for the largest ones. The hydrogen concentration could be maintained below its lower flammable limit by purging the containment atmosphere to the environs at a controlled rate after the LOCA; however, radioactive materials in the containment would also be released. If purging became necessary shortly after the accident, quantities of such material would be released. The staff believes that the capability for controlled purging should be provided, but that purging should not be the primary means for controlling combustible gases following a LOCA.

The Bureau of Mines has conducted experiments at their facilities with initial hydrogen volume concentrations in the range of four to twelve volume percent. On the basis of these experiments, and of review of reports by others, the staff concludes that a lower flammability limit of four volume percent hydrogen in air or steam-air atmospheres is well established and is adequately conservative. For initial concentrations of hydrogen greater than about six volume percent, it is possible in the presence of sufficient ignition sources that the total accumulated hydrogen could burn in the containment. For hydrogen concentrations in the range of four to six volume percent, partial burning of the excess hydrogen above four volume percent may occur. The staff believes that a limit of six volume percent would not result in effects that would be adverse to containment systems. Applicants or licensees should demonstrate through supporting analyses and experimental data that containment features and safety equipment required to operate a LOCA would not be made inoperative by burning of the excess hydrogen, if a design limit in the range of four to six volume percent hydrogen is proposed.

In small containments, the amount of metal-water reaction postulated in Table 1 may result in hydrogen concentrations above acceptable limits. The evolution rate of hydrogen from the metal-water reaction would be greater than that from either radiolysis or corrosion, and since it is difficult for a hydrogen control system to process large volumes of hydrogen very rapidly, an alternative approach is to operate some of the smaller containments with inert (oxygen deficient) atmospheres. This measure, the so-called "inerting" of a containment, provides sufficient time for combustible gas control systems to reduce the concentration of hydrogen following a loss-of-coolant accident before the oxygen generated by radiolysis results in flammable mixtures in the containment. Any requirement for inerting of a containment should be considered on an individual case basis, taking into account the features of the plant, the details of the inservice inspection program for components inside containment, and the need for protection against possible effects from combustible gases.

For all containments, it is advisable to provide means for mixing, sampling, and control of combustible gases resulting from the postulated metal-water reaction, radiolysis, and corrosion following a LOCA, which do not involve releases of radioactive materials to the environment. It is also advisable, as a back-up measure, to provide the capability of purging the containment. Filters should be provided as needed in the purge stream to limit the potential release of radioactive iodine and other radioactive materials so that the calculated radiological consequences of the LOCA, including the purge, do not exceed the guideline doses given in 10 CFR Part 100.

Since any system for combustible gas control is designed for the protection of the public in the event of an accident, it should meet the design and construction standards of engineered safety features. Care should be taken in its design to assure that the system itself does not introduce safety problems that may affect containment integrity; for example, if a flame recombiner is used, propagation of flame into the containment should be prevented.

For most reactor plants, operation of the hydrogen control system would not be required for time periods of the order of seven days or more following a postulated design basis LOCA. Thus, it is reasonable that hydrogen control systems need not necessarily be installed at each reactor. Provision for either onsite or offsite storage or a shared arrangement between licensees of plants in close proximity to each other may be developed. An example of an acceptable arrangement would be to provide at least one hydrogen control system per site with the provision that a redundant unit would be available from a nearby site.

B. BRANCH TECHNICAL POSITION

1. All water-cooled power reactor facilities should have the capability for measurement of the hydrogen concentration, for mixing the atmosphere in the containment, and for controlling combustible gas concentrations without reliance on purging of the containment atmosphere following a loss-of-coolant accident.

2. The continuous presence of combustible gas control equipment at the site may not be necessary provided it is available on an appropriate time scale; however, appropriate design and procedural provisions should be made for its use. In addition, centralized storage facilities that would serve multiple sites may be used provided that these facilities include provisions such as maintenance, protective features, testing, and transportation for redundant units to a particular site.

3. Combustible gas control systems and the provisions for mixing, measuring, and sampling should meet the design, quality assurance, redundancy, energy source, and instrumentation requirements for an engineered safety feature, and the system itself should not introduce safety problems that may affect containment integrity. The combustible gas control system should be designated seismic Category I (See Regulatory Guide 1.29), and the Group B quality standards of Regulatory Guide 1.26 should be applied.

4. All water-cooled power reactors should also have the installed capability for a controlled purge of the containment atmosphere. The purge system need not be redundant nor be designated seismic Category I, except insofar as portions of the system constitute part of the primary containment boundary. Filtration of the purge stream should be provided as necessary to reduce the sum of the long-term doses from the LOCA and the purge to values less than the guidelines of 10 CFR Part 100 at the low population zone outer boundary.

5. The parameter values listed in Table 1 should be used for the purpose of calculating hydrogen and oxygen gas concentrations in containments and evaluating designs provided to control and to purge combustible gases evolved in the course of loss-of-coolant accidents. These values may be changed on the basis of additional experimental evidence and analyses.

6. 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 practical.

7. For plants for which a notice of hearing on the application for a construction permit was published after November 5, 1970:

   a. Plants recieving operating licenses on the basis (in part) of ECCS evaluations under §50.46 should conform to items 1-6, above, prior to operation.

   b. Plants receiving operating licenses on the basis (in part) of ECCS evaluations under the Interim Policy Statement of June 29, 1971, should conform, prior to operation, to items 1-6, above, but with item 4 of Table 1 changed to specify a five percent metal-water reaction and an evolution time determined on an individual case basis.

      Reevaluations of combustible gas control measures for plants in this category to take account of the change in amount of assumed metal-water reaction may be made at the option of applicants and licensees after submission of §50.46 ECCS analyses and final approval by the staff.

   c. Designs of plants receiving construction permits on the basis (in part) of ECCS evaluations under §50.46 should include combustible gas control measures in conformance with items 1-6, above.

d. Designs of plants receiving construction permits on the basis (in part) of ECCS evaluations under the Interim Policy Statement of June 29, 1971, should include combustible gas control measures that conform, at the option of applicants, to one of the following:

   (1) Items 1-6, above, based on a commitment to a specified maximum metal-water reaction to be calculated according to §50.46.

   (2) Items 1-6, above, but with item 4 of Table 1 changed to specify a five percent metal-water reaction and an evolution time determined on an individual case basis.

8. For plants for which a notice of hearing on the application for a construction permit was published between December 22, 1968 and November 5, 1970:

   a. A redundant combustible gas control system (such as a recombiner system) as described in items 1 and 2, above, or a repressurization system[1/] designed with redundant elements and designated seismic Category I should be provided unless purging doses are less than the limits given in subparagraph (b), below. Purging capability should also be provided as a backup measure to a combustible gas control system, but in this case no purging dose computations need be submitted and the purging system need not have redundant elements or be designated seismic Category I, except insofar as portions of the system constitute part of the primary containment boundary.

   b. If the incremental long-term doses from purging in the event of a postulated LOCA are calculated to be less than 2.5 rem whole body and 30 rem thyroid at all points beyond the exclusion area boundary, no combustible gas control systems other than the purging system need be provided. The combination of the dose from the purge and the long-term dose from a postulated LOCA should be below the guidelines of 10 CFR Part 100 at the low population zone outer boundary. Any filtration system for which credit is taken in calculating the purging dose should be redundant, should be designated seismic Category I, and the Group B quality standards of Regulatory Guide 1.26 should be applied. Such filtration systems should be designed, constructed, and tested to meet the recommendations of Regulatory Guide 1.52 to the extent practical. The purging system should be designed to that it is not made inoperative by the failure of any single active component (such as a valve, blower, or electrical power source).

[1/] Provisions such as a containment atmospheric dilution system that introduces additional gas into the drywell of some BWR plants may be provided to delay the time to purge on plants in this category; however, the containment should not be repressurized beyond 50% of the containment design pressure.

c. For plants receiving operating licenses on the basis (in part) of ECCS evaluations under §50.46, the parameter values listed in Table 1 should be used to calculate combustible gas concentrations in containments and to evaluate designs provided to control and to purge these gases.

For operating plants, or plants receiving operating licenses on the basis (in part) of ECCS evaluations under the Interim Policy Statement of June 29, 1971, the parameter values of Table 1 should be similarly used, with item 4 of Table 1 changed to specify a five percent metal-water reaction and an evolution time determined on an individual case basis. Reevaluations of combustible gas control measures for plants in this category to take account of the change in amount of assumed metal-water reaction may be made at the option of applicants and licensees after submission of §50.46 ECCS analyses and final approval by the staff.

d. Combustible gas control systems conforming to this section (B.8) should be provided prior to operation or as soon thereafter as practical.

9. For plants for which a notice of hearing on the application for a construction permit was published before December 22, 1968:

a. Information regarding the calculated dose from purging should be furnished to the staff. If the sum of the long-term doses from a postulated LOCA and the purging dose is below the guidelines of 10 CFR Part 100 at the low population zone outer boundary, no combustible gas control systems other than the purging system need be provided.

b. Any filtration system for which credit is taken in calculating the purging dose should be redundant and designated seismic Category I, and the Group B quality standards of Regulatory Guide 1.26 should be applied. Such filtration systems should be designed, constructed, and tested to meet the recommendations of Regulatory Guide 1.52 to the extent practical.

c. The purging system should be designed so that it is not made inoperative by the failure of any single active component (such as a valve, blower, or electrical power source).

d. If the long-term dose limit of subparagraph (a) cannot be met by a purging system with filtration, either a redundant combustible gas control system (such as a recombiner system) as described in items 1 and 2, above, or a repressurization system[1/] with redundant elements and designated seismic Category I should be provided. Purging capability should also be provided as a backup measure for the combustible gas control system, but the purging system need not have redundant filters, be designated seismic Category I, except insofar as portions of the system constitute part of the primary containment boundary, or meet the single failure or long-term dose limit criteria, above.

[1/] Ibid., page 21.

e. For plants receiving operating licenses on the basis (in part) of ECCS evaluations under §50.46, the parameter values listed in Table 1 should be used to calculate combustible gas concentrations in containments and to evaluate designs provided to control and to purge these gases.

For operating plants, or plants receiving operating licenses on the basis (in part) of ECCS evaluations under the Interim Policy Statement of June 29, 1971, the parameter values of Table 1 should be similarly used, with item 4 of Table 1 changed to specify a five percent metal-water reaction and an evolution time determined on an individual case basis. Reevaluations of combustible gas control measures for plants in this category to take account of the change in amount of assumed metal-water reaction may be made at the option of applicants and licensees after submission of §50.46 ECCS analyses and final approval by the staff.

f. Schedules for installation of purging systems or other combustible gas control systems should be considered on an individual case basis.

C. REFERENCES

The references for this branch technical position are the same as those for Standard Review Plan 6.2.5, given in Section V of the plan.

TABLE 1

1.	Fraction of fission product radiation energy absorbed by the coolant[1]	a. Beta (1) Betas from fission products in the fuel rods: 0 (2) Betas from fission products intimately mixed with coolant: 1.0 b. Gamma (1) Gammas from fission products in the fuel rods, coolant in core region: 0.1[2] (2) Gammas from fission products intimately mixed with coolant, all coolant: 1.0
2.	$G(H_2)$[1]	0.5 molecules/100 ev
3.	$G(O_2)$[1]	0.25 molecules/100 ev
4.	Extent and evolution time of initial core metal-water reaction hydrogen production from the surrounding fuel.	Hydrogen production is 5 times the amount from the maximum calculated reaction under 10 CFR §50.46, or that amount that would be evolved from a core-wide average depth of reaction into the original cladding of 0.00023 inches, whichever is greater, in 2 minutes.
5.	Aluminum corrosion rate for aluminum exposed to alkaline solutions.	200 mils/yr (This value should be adjusted upward for higher temperatures early in the accident sequence)
6.	Fission product distribution model.	a. 50% of the halogens and 1% of the solids present in the core are intimately mixed with the coolant water. b. All noble gases are released to the containment. c. All other fission products remain in fuel rods.
7.	a. Hydrogen concentration limit.	4 volume percent[3]
	b. Oxygen concentration limit.	5 volume percent (This limit should not be exceeded if more than 6 v/o hydrogen is present.)

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[1] For water, borated water, and borated alkaline solutions; for other solutions, data should be presented.

[2] This fraction is thought to be conservative; further analysis may show that it should be revised.

[3] The 4 v/o hydrogen concentration limit should not be exceeded if burning is to be avoided and more than 5 v/o oxygen is present in containment.

This amount may be increased to 6 v/o, with the assumption that the 2 v/o excess hydrogen would burn in the containment (if more than 5 v/o oxygen is present). The effects of the resultant energy and burning should not create conditions exceeding the design conditions of either the containment or safety equipment necessary to mitigate consequences of a LOCA. Applicants and licensees should demonstrate such capability by suitable analyses and qualification test results.

SRP 6.2-6