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(Formerly NUREG-75/087)

U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

6.2.5 COMBUSTIBLE GAS CONTROL IN CONTAINMENT

REVIEW RESPONSIBILITIES

Primary - Containment Systems Branch (CSB)

Secondary - None

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 to assure conformance with the requirements of General Design Criteria 41, 42 and 43. 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.

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 stage of review) for periodic inservice inspection, operability testing and leak rate 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.

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 in subsection II of this SRP section.

CSB will coordinate other branch evaluations that interface with the overall review of the combustible gas control matter, as follows: The Mechanical Engineering Branch (MEB) will review seismic design and quality group classifications as part of its primary review responsibility for SRP Section 3.2.1 and SRP Section 3.2.2, respectively. The Instrumentation and Control Systems Branch (ICSB), as part of its primary review responsibility for SRP Section 7.5, will evaluate the actuation and control features of active components. The Equipment Qualification Branch (EQB), as part of its primary review responsibility for SRP Section 3.11, will evaluate the qualification test program for electric valve operators, fans, hydrogen/oxygen sampling or analyzing equipment, and sensing and actuation instrumentation of the plant protection system, located both inside and outside the reactor containment. The Chemical Engineering Branch (CMEB), as part of its primary review responsibility for SRP Section 6.1.1, will generically evaluate the corrosion rates of materials (such as galvanized steel and aluminum) exposed to containment spray solutions. The CMEB, as part of its primary review responsibility for SRP Section 6.1.2, will evaluate the hydrogen generation rates from the radiation decomposition of organic materials (such as primers/coatings and cable insulation), and the corrosion rates of materials (such as zinc-based primers) exposed to containment spray solutions. CSB will request CMEB participation in the evaluation of analyses of hydrogen generation from the radiolysis of reactor coolant and sump water when such analyses by applicants do not follow the guidance of Appendix A to this SRP section. The Radiological Assessment Branch (RAB), as part of its primary review responsibility for SRP Section 12.3, will evaluate the accessibility of combustible gas control systems equipment under postulated accident conditions. The Licensing Guidance Branch (LGB), as part of its primary review responsibility for SRP Section 16.0, will review, at the operating license stage of review, proposed technical specifications pertaining to the operability and leakage rate testing of systems and components.

For those areas of review identified above as being reviewed as part of the primary review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding primary branch.

II. ACCEPTANCE CRITERIA

CSB acceptance criteria for the design of the systems provided for combustible gas control are the relevant requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and General Design Criteria 5, 41, 42 and 43. The requirements are as follows:

a. § 50.44 and § 50.46 of 10 CFR Part 50 as it relates to BWR and PWR plants being designed to (a) include means for control of hydrogen that may be generated, following a LOCA, by core metal-water reaction, radiolytic decomposition of water and corrosion of water and corrosion of metals; (b) be provided with the capability for measuring the hydrogen concentration in the containment, insuring a mixed containment atmosphere and controlling combustible gas concentrations in the containment; and (c) be provided with an inerted atmosphere or an oxygen deficient condition if certain conditions cannot be met prior to effective operation of the combustible gas control system. Postaccident 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. As a result of the TMI-2 accident a reevaluation of the hydrogen that may be generated following an accident is being undertaken. Item II.B.8 of NUREG-0694 and NUREG-0718 discuss the rulemaking proceedings on degraded core accidents for the different classes of plants. 10 CFR Part 50 will be revised to include the additional requirements for hydrogen control systems and the amounts of hydrogen these control systems will have to accomodate.

b. General Design Criterion 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.

c. General Design Criterion 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 assure that containment integrity is maintained; systems being designed to safety-grade requirements; i.e., that there be suitable redundancy in components and features, and suitable interconnections to assure 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 assure that system safety function can be accomplished.

d. General Design Criterion 42 as it relates to the design of the systems to permit appropriate periodic inspection of components to assure the integrity and capability of the systems.

e. General Design Criterion 43 as it relates to te systems being designed to permit periodic testing to assure system integrity, and the operability of the systems and active components.

Specific criteria necessary to meet the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 5, 41, 42 and 43, are as follows:

1. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 41 to provide systems to control the concentration of hydrogen or oxygen in the containment atmosphere following postulated accidents, the analysis of hydrogen and oxygen production should be based on the parameters listed in Table 1 of Regulatory Guide 1.7 for the purpose of establishing the design basis for combustible gas control systems.

2. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 41 to provide systems to control the concentration of hydrogen or oxygen in the containment atmosphere following postulated accidents, 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 ASB 9-2 in SRP Section 9.2.5.

3. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 to provide the capability for insuring a mixed atmosphere in the containment, and of GDC 41 to provide systems as necessary to assure that containment integrity is maintained, 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 combustible mixture.

4. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 41 regarding the functional capability of the combustible gas control systems to assure that containment integrity is maintained, 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 Regulatory Guide 1.7. Acceptance of the functional capability of the systems is based on confirmatory analyses performed by CSB using the COGAP code as described in the Appendix A of this SRP section and the 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 appropriate 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 is 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.

5. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 41 regarding the functional capability of the combustible gas control systems to assure that containment integrity is maintained, system components such as ductwork and equipment housings, e.g., for fans, fan coolers, filters, and recombiners, should be capable of withstanding all related environmental conditions imposed on them, including external transient differential pressures and internal 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.

6. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 and GDC 41 regarding the functional capability of the combustible gas control systems to assure that containment integrity is maintained, 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. The containment penetrations needed for plants that utilize external recombiners must meet the requirements of Item II.E.4.1 of NUREG-0737 and NUREG-0718.

7. To satisfy the design requirements of GDC 41, combustible gas control systems should be designed, fabricated, erected, and tested to Group B quality standards, as recommended in Regulatory Guide 1.26.

8. To satisfy the design requirements of GDC 41, 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.

9. To satisfy the design requirements of GDC 41, performance tests should be performed on system components, such as hydrogen recombiners, and combustible gas analyzers. The tests should support the analyses of the functional capability of the equipment.

10. 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. The inspection and test program is acceptable if it is judged to be consistent with that proposed for other engineered safety features.

11. To satisfy the design requirements of GDC 41, 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 monitor shall meet the requirements of Item II.F.1 of NUREG-0737 and NUREG-0718, and the Appendix of Regulatory Guide 1.97.

12. In meeting the requirements of GDC 5 regarding the sharing of system equipment between nuclear power units at a multi-unit site or between sites, sharing is acceptable provided (a) the shared equipment can be made available to perform its function in a time period that is equal to or less than one-half the time before it is required to operate and (b) surveillance programs are coordinated to assure that redundant equipment is not out of service at the same time. Regulatory Guide 1.7 provides additional guidance on the sharing of equipment.

13. In meeting the requirement of 10 CFR Part 50, §§ 50.44 and 50.46 to provide the capability for controlled purging of the containment to aid in post-accident cleanup, the guidance provided in Regulatory Guide 1.7 should be followed.

14. In meeting the requirements of 10 CFR Part 50, §§ 50.44 and 50.46 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 construction permit stage of review if the guidelines of Regulatory Guide 1.7 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 assure that this review procedure is complete.

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 assure that the recommendations and guidelines of Regulatory Guide 1.7 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 Regulatory Guide 1.7 (the Regulatory Guide 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 SRP section. 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 Regulatory Guide 1.7.

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 subsection 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 qualification testing of systems and components, to establish the functional capability of the equipment.

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 requirements 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. CSB reviews the containment penetrations needed for plants that utilize external recombiners to assure the single failure criteria outlined in Item II.E.4.1 of NUREG-0737 or NUREG-0718 are met.

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 SRP Section 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 Regulatory Guide 1.7 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.

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 performance of the combustible gas control systems are acceptable and meet the requirements of 10 CFR Part 50, § 50.44 and § 50.46 and Criteria 5, 41, 42 and 43. This conclusion is based on the following: [The reviewer should discuss each item of the regulations or related set of regulations as indicated.]

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.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding NRC staff plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to the method described herein are contained in the referenced Regulatory Guides.

VI. REFERENCES

1. 10 CFR Part 50, § 50.44, "Standards for combustible gas control system in light water cooled power reactors." Also, 10 CFR Part 50, § 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Cooled Reactors."

2. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems and Components."

3. 10 CFR Part 50, Appendix A, General Design Criterion 41, "Containment Atmosphere Cleanup."

4. 10 CFR Part 50, Appendix A, General Design Criterion 42, "Inspection of Containment Cleanup System."

5. 10 CFR Part 50, Appendix A, General Design Criterion 43, "Testing of Containment Atmosphere Cleanup System."

6. Regulatory Guide 1.7, "Control of Combustible Gas Concentrations in Containment Following a Loss-of-Coolant Accident."

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

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

9. 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.

10. 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.

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

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

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

14. NUREG-0094, "TMI-Related Requirements for New Operation Licensees," June 1980.

15. NUREG-0718, "Licensing Requrements for Pending Applications for Construction Permits and Manufacturing License," March 1981.

16. NUREG-0737, "Classification of TMI Action Plan Requirements."

APPENDIX A
SRP SECTION 6.2.5
DESCRIPTION OF GOGAP

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. Zinc 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 zirconium-water reaction and associated hydrogen production depends strongly upon the course of events assumed for the accident. Analytically the reaction can be described by:

$$Zr + 2H_2O \text{ T } ZrO_2 + 2H_2$$

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

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

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:

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

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

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

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:

$$E_c(t) = (f_q)_c\ H_q(t)$$

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 ASB 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 aluminimum corrosion is normally considered only when additives are used in the cooling solution. When applicable, gas production is governed by the following expression:

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

Where

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

A = surface area of aluminum, ft^2

p = 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 is treated in a similar fashion.

<u>COGAP INPUT REQUIREMENTS</u>

COGAP has been developed to minimize the required input information. All data associated with the power decay profile have been incorporated into the program and need not be entered.

The major input requirements are:

1. Reactor power level, Mwt.
2. Containment free volume, ft^3.
3. Second containment free volume, (wetwell), ft^3.
4. Zirconium cladding weight, pounds.
5. Oxygen dissolved in primary, pound-moles.
6. Hydrogen dissolved in primary, pound-moles.
7. Initial containment pressure, psia.
8. Initial containment temperature, Rankine.
9. Initial oxygen volume fraction (.209).

10. Recombiner flow rate, cfm.

11. Time recombiner is started, days.

12. Purge rate, cfm.

13. Zirc-water reaction fraction.

14. Aluminum surface area, ft^2.

15. $G\text{-}H_2$, core solution, mole/100 ev.

16. $G\text{-}H_2$, sump solution, mole/100 ev.

17. Fraction of gammas absorbed in coolant in core region.

18. Fraction of solid fission product energy absorbed in solution outside core.

19. Fraction of iodine fission product energy absorbed in solution outside core.

20. Time constant, 9.0×10^8.

21. H_2 concentration fraction at which purging will begin.

22. Time to initiate nitrogen addition, sec.

23. CAD nitrogen flow rate, scf/sec.

BRANCH TECHNICAL POSITION CSB 6-2

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

(BTP CSB 6-2 has been superseded by Regulatory Guide 1.7.)