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pwr and bwr containment spray system design criteria

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ERRATUM

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Equation 8.3.6-2, page 21

$$\bar{d}_{IR} = \left[\frac{\sum_{i=1}^n f(d_i) d_i^{-2.2}}{\sum_{i=1}^n f(d_i)} \right]^{-\frac{1}{2.2}} \quad (\text{Eq. 8.3.6-2})$$

should have the negative signs on both of the exponents deleted. It should read

$$\bar{d}_{IR} = \left[\frac{\sum_{i=1}^n f(d_i) d_i^{2.2}}{\sum_{i=1}^n f(d_i)} \right]^{\frac{1}{2.2}} \quad (\text{Eq. 8.3.6-2})$$

ANSI/ANS-56.5-1979

**American National Standard
for PWR and BWR Containment
Spray System Design Criteria**

**Secretariat
American Nuclear Society**

**Prepared by the
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Foreword

(This Foreword is not a part of American National Standard for PWR and BWR Containment Spray System Design Criteria, ANSI/ANS-56.5-1979.)

The first meeting of the working group was held in the spring of 1975. During the preparation of the first outlines, the working group was confronted with a basic problem of how to write a design criteria standard that would apply to both PWR and BWR Containment Spray Systems. The working group addressed this problem by discussing all functions of the Containment Spray System and then prefacing appropriate sections by limiting statements, such as: "for iodine removal purposes," or "for pressure suppression purposes." It was felt that such an approach would allow the designer to select the appropriate portions of the standard.

Another fundamental goal was the attainment of a standard that would provide clear and detailed guidance to the designer. Thus, the document attempts to present all necessary design considerations. When the state-of-the-art technology indicates a preferred method, the standard will suggest that method. Although it is desirable to give the designer flexibility, it was the goal of the group to draft a standard that would encourage standard high quality designs. As a consequence, most of the criteria are requirements. When several equivalent approaches exist, flexibility is preserved. Backup information for fission product removal calculations is included as an Appendix to the standard.

This standard employs a technique using a discrimination device called "boxing." This technique indicates those statements which are nuclear safety related. The term "nuclear safety" includes those requirements that are felt by the writing group to arise from official and implied NRC policies (including regulations, regulatory guides, branch positions, the Standard Review Plan, and past practice on applications) *as well as* other requirements the group believes are related to nuclear safety. Non-nuclear safety related requirements include the following types of needs as they exclusively apply to areas not considered to be nuclear safety related: conventional safety, equipment reliability, plant availability, good engineering practice, and contractual (commercial) requirements.

During the preparation of this standard, the membership of ANS-56.5 was as follows:

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PWR and BWR Containment Spray System Design Criteria

1. Scope

This standard provides the design, performance, testing, maintenance, and instrumentation and control requirements for the containment spray system for boiling water and pressurized water reactor stationary electric generating plants.

The containment spray system, consisting of a spray subsystem and an additive subsystem, serves to mitigate the consequences of a loss of coolant accident, a PWR feedwater line or a PWR steam line break, by injecting a water spray into the containment atmosphere. The containment spray system may be used to aid safety by performing one or more of the following functions:

- (1) Containment Post-Accident Pressure Suppression
- (2) Containment Post-Accident Heat Removal
- (3) Containment Atmosphere Post-Accident Fission Product Removal
- (4) Post-Accident Mixing of Containment Atmosphere
- (5) Post-Accident Containment Sump Chemistry Control.

2. Purpose

The purpose of this standard is to define the design requirements for a water spray system within LWR containment that provides the necessary coolant to reduce the pressure, remove heat and fission products, provide sump chemistry control and post-accident atmosphere mixing following a loss-of-coolant accident.

3. Definitions

acceptable. The word "acceptable" is used when a system or component has been demonstrated to meet its design and performance criteria by test or analysis.

active component. A mechanical component in which physical movement must occur upon demand in order to perform the component's intended function.

active failure. A malfunction, excluding passive failures, of a component which relies on mechanical movement to complete its intended function upon demand.

Examples of active failures include the failure of a valve or check valve to move to its correct position or the failure of a pump, fan, or diesel generator to start.

Spurious action of a powered component originating within its actuation or control system shall be regarded as an active failure unless specific design features or operating restrictions preclude such spurious action. An example is the unintended energizing of a powered valve to open or close. Additional guidance is provided in American National Standard Single Failure Criteria for PWR Fluid Systems, N658-1976 (ANS-51.7). [1]¹

(This concept of active failure and passive failure currently does not apply to electrical components.)

additive. In the context of containment spray systems, any substance added to the spray water to adjust pH or enhance fission product removal.

additive subsystem. That portion of the containment spray system which is specifically designed to place additive(s) into the spray water during spray operation.

containment. See primary reactor containment.

¹Numbers in brackets refer to corresponding numbers of Section 9, References.

cooling water. Water provided to transfer the heat absorbed by the containment heat removal system to the ultimate heat sink.

fission product removal. In the context of this standard, the process of removing fission products from the post-accident containment atmosphere.

functional test. A qualitative or quantitative determination of acceptable operability by observation of system or component behavior during operation.

independent. The word "independent" is used to indicate the freedom from and unsusceptibility to failure resulting from interaction among redundant safety-related components and systems.

injection mode. In the context of this standard with regard to the spray subsystem, the operating condition in which water is sprayed into the containment atmosphere from the injection water supply. With regard to the additive subsystem, the operating condition in which additive is added to the spray water.

injection water supply (PWR). A water storage structure from which water is drawn for the injection mode.

long term. In the context of the single failure criteria, that period of system operation, following the short term, during which the safety function of the system is required.

(The concept of short term and long term does not apply to electrical components.)

natural hazard. A natural phenomenon which has the potential for causing damage to the safety-related structures, systems, or components of a unit.

operational. Capable of performing an intended action in the required manner.

operating floor. For BWR's, this term is defined as the refueling floor for MKIII and the grating level at the personnel hatch just above the drywell floor for MKII containments. For

PWR's this term is defined as the floor at the same level as the personnel hatch.

partition coefficient. The dimensionless ratio of the iodine concentration in the liquid phase to the iodine concentration in the gas phase at equilibrium based on volume.

passive component. A mechanical component which does not require physical movement in order to perform its intended function.

passive failure. A failure of a component to maintain its structural integrity or the blockage of a process flow path.

post-accident environment. In the context of this standard, the temperature, pressure, humidity, radiation, chemistry, and contamination levels of a containment after an accident.

pressure suppression. A means to reduce containment pressure by condensation of the steam through contact with water, ice, or other cooling surfaces.

primary reactor containment. The principal design feature of a unit that acts as the principal barrier, after the reactor coolant pressure boundary or primary coolant boundary, to control the release under all Conditions of Design, of radioactive material. It includes (1) the containment structure, and its access openings, penetrations, and appurtenances, (2) those valves, pipes, closed systems, and other components used to effect isolation of the containment atmosphere from the environment, and (3) those systems or portions of systems that, by their functions, extend the containment structure boundary to include their system boundary (e.g., in a PWR, the boundaries of the secondary side of the steam generator and the connecting steam and feedwater piping).

recirculation mode. In the context of this standard, that configuration of the containment spray system in which water is taken from a containment sump and returned to the containment atmosphere.

redundant component, system or sub-

system. A component, system or subsystem that independently duplicates the essential function of another component, system, or subsystem.

seismic category I. The seismic classification of structures, systems, and components that are required to remain functional if an SSE occurs.

shall, should, and may. The word "shall" is used to denote a requirement, the word "should" to denote a recommendation, and the word "may" to denote permission, neither a requirement nor a recommendation.

short term. In the context of this standard, that period of operation following an initiating event required to complete the injection mode (for both spray and additive subsystems) or 24 hours, whichever is less.

spray thermal effectiveness. The ratio of heat transferred from the containment atmosphere to the spray, to that heat transfer corresponding to thermal equilibrium

$$\epsilon_t = \frac{h_{sf} - h_{si}}{h_{ca} - h_{si}}$$

where:

h_{sf} = spray enthalpy after being heated by the containment atmosphere

h_{si} = spray water enthalpy at nozzles

h_{ca} = enthalpy of the spray water at thermal equilibrium with the containment atmosphere

spray subsystem. That portion of the containment spray system which is specifically designed to deliver water to the post-accident containment atmosphere.

sump. A structure in the containment provided to collect water after an accident, for the recirculation mode. The sump may also be a pressure suppression pool (BWR).

4. System Safety Functions

The primary function of the containment spray system is to spray water solution into the containment atmosphere in the event of a loss-of-

coolant accident (LOCA), a PWR feedwater line or a PWR steam line break. The potential safety functions for which this system may be designed to accomplish are described below.

4.1 Pressure Suppression. The containment spray system can be designed to accomplish pressure suppression during either or both the injection and the recirculation modes following an accident to maintain the containment pressure below the design value.

4.2 Heat Removal. After an accident, the containment spray system can be used to remove heat from the containment, i.e., a heat exchange function.

4.3 Fission Product Removal. The containment spray system can be used to remove airborne fission products from the containment atmosphere, thus reducing the inventory of airborne fission products (primarily iodine) available for leakage to the environment. This function may be enhanced by chemical addition to the spray for improved iodine removal.

4.4 Sump Chemistry Control. Since the spray water is ultimately collected in a containment sump, chemical addition to the spray can be utilized to control the chemistry of the sump both for long term iodine retention and, if required, for long term corrosion control.

4.5 Post-Accident Atmosphere Mixing. The spray system can be used for containment atmosphere mixing to prevent local buildup of combustible gases following a loss-of-coolant accident. This function will not be addressed further in this standard.²

5. System Definition

The containment spray system is functionally separated into two subsystems, the spray subsystem and the additive subsystem. The spray subsystem will be present in all designs, while

²This area will be covered in the proposed American National Standard "Containment Hydrogen Control," under development by ANS-56.1. Assigned Correspondent: N.B. Willoughby, Bechtel Power Corporation, 15740 Shady Grove Road, Gaithersburg, MD 20760.

the additive subsystem will be present in some designs.³

5.1 Spray Subsystem

5.1.1 Subsystem Boundaries. For the purpose of this standard, the spray subsystem is considered to begin at, but not include, the injection water supply. The boundary extends to and includes the spray nozzles. The boundary also extends to, but does not include, the containment sump. The sump is replaced by the suppression pool for BWR designs.

5.1.2 Subsystem Components. The major components of the spray subsystem are the containment spray pumps and motors, process piping, valves and valve operators, spray nozzles, and associated instruments and controls. Heat exchangers may be included in some designs.

5.1.3 Interfaces. The spray subsystem interfaces with other systems either by physical connection or by functional dependence. Physical interfaces can occur with the residual heat removal systems, containment sump, the additive subsystem, borated water storage tanks (or the BWR suppression pool), cooling water systems, the engineered safety features actuation system, and emergency power supplies. Functional interfaces can occur with independent systems which perform redundant functions, such as fan cooling systems for PWR post-accident heat removal. The system designer shall ensure that all required interfaces have the appropriate safety class.

5.2 Additive Subsystem

5.2.1 Subsystem Boundaries. For the purpose of this standard, the additive subsystem boundary starts with the additive tank(s) and extends to the spray subsystem boundary.

5.2.2 Subsystem Components. The major components of the additive subsystem are the additive tank(s), process piping, valves, valve operators, and associated instruments and controls. Additive pumps or eductors are included in some designs.

5.2.3 Interfaces. The additive subsystem interfaces with the spray subsystem, and may interface with other plant systems such as heat tracing, inert cover gas supply, emergency power

supplies, and the engineered safety features actuation system.

6. System Performance Requirements

6.1 Pressure Suppression. The containment spray system is an active system which can be used alone, or in conjunction with other active and passive systems, to control containment pressure following a major mass/energy release within the containment.

Passive systems acting as energy sinks which can be used to control containment pressure include, but are not limited to:

- (1) Containment structures and equipment
- (2) Containment air mass
- (3) Pools of water
- (4) Chambers of ice.

Other active means of pressure suppression may be used in conjunction with or in place of containment sprays. One such alternative means is the use of containment fan cooling units. For additional guidance see the American National Standards for Boiling Water Reactor Containment Ventilation Systems, ANSI/ANS-56.7-1978, and for Pressurized Water Reactor Containment Ventilation Systems, ANSI/ANS-56.6-1978. [2,3]

6.1.1 Containment Spray Flow. Upper and lower flow limits shall be defined for the containment spray system.

Minimum spray flow rates shall be defined for the purpose of evaluating maximum containment pressure.

Maximum spray flow rates shall be defined for the evaluation of minimum containment pressure for use in analysis of Emergency Core Cooling System Acceptance and for use in establishing the negative differential pressure for containment structural design.

A tested and certified pump performance curve shall be used for final evaluation of these parameters. For additional information see 7.4.

6.1.2 Containment Spray Temperature. The spray temperature assumed for maximum containment pressure calculation shall be a maximum value. Conversely, the minimum containment pressure calculation shall be based

³Typical flow diagrams for the two subsystems are shown in Appendix A.