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**airborne release fractions at
non-reactor nuclear facilities**

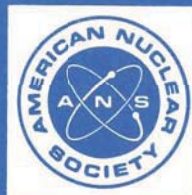
REAFFIRMED

**January 15, 2013
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an American National Standard

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**American National Standard for
Airborne Release Fractions at
Non-Reactor Nuclear Facilities**

Secretariat
American Nuclear Society

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Standards Committee
Working Group ANS-5.10**

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Foreword

(This Foreword is not a part of American National Standard for Airborne Release Fractions at Non-Reactor Nuclear Facilities, ANSI/ANS-5.10-1998.)

Techniques for assessing potential downwind impacts of radionuclides released from nuclear facilities have evolved since the inception of the nuclear industry. The techniques have become more rigorous as well as more numerous. The many techniques applied in safety analyses have often resulted in divergent estimates of the downwind impacts from identical or very similar postulated events. Guidance toward more standard techniques for radionuclide release analysis is needed so that estimates can be compared in a meaningful fashion.

One technique used in evaluating the potential downwind impacts is the selection of an Airborne Release Fraction (ARF), which is the amount of the radioactive or hazardous material-of-concern made airborne through specific postulated accident stresses. This standard provides guidance for a consistent selection and application of ARFs in accident analyses.

The complexity of any actual situation precludes an analytical determination of the ARF. Thus, estimates from experimental data generally have been identified for specific materials (such as plutonium and uranium) or for physically similar materials (such as liquids, powders, or contaminated combustibles) under accident-induced types and levels of stress. ARFs derived from data are used to estimate the amount of a material-of-concern made airborne by thermal, aerodynamic, or mechanical stress over time periods ranging from seconds for explosively generated ARFs, hours for a fire, or potentially very long periods of time for aerodynamic stress. The applicability of experimentally derived ARFs is limited to the range covered in the experimental study. Experimental data are limited for some of the initiator-response sequences and values are also inferred from other experimental studies that appear to impose the same type and level of stress upon similar materials. As the need arises, additional data and information may be generated to improve or revise the ARFs.

Actual accidents are unique events that cannot be accurately defined, and it would be misleading to leave the impression that estimates of the potential impacts based upon analyses can be very accurate. Therefore, ARFs must be viewed as tools to provide estimates of airborne release but, due to the lack of accuracy in defining the response and behavior of other components, highly accurate ARFs do not assure highly accurate estimates of airborne release.

This standard was prepared by Working Group ANS-5.10 of the Standards Committee of the American Nuclear Society. Continuing efforts will be required to augment or modify the criteria in this standard and to implement additional information and experimental studies as they become available.

Working Group ANS-5.10 had the following membership at the time it developed this standard:

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Airborne Release Fractions at Non-Reactor Nuclear Facilities

1. Scope and Purpose

1.1 Scope. This standard provides criteria for defining Airborne Release Fractions (ARFs) for radioactive materials under accident conditions (excluding nuclear criticalities) at non-reactor nuclear facilities. The criteria in this standard provide requirements for selecting ARFs based on the calculated or assumed forms of radioactive material released. This standard may be applied to determine the ARFs for certain applicable reactor plant events for which alternative methodologies are not mandated by regulatory requirements. Because the predominant physical forms of radioactive materials in non-reactor facilities are solids and liquids, the standard focuses on these forms. Criteria are also provided for gases and materials that can be converted into the form of a vapor.

1.2 Purpose. This standard addresses criteria for selecting appropriate ARFs to estimate the airborne release from accident phenomena that can subdivide and suspend radioactive materials from various initiating events. The purpose of this standard is to provide a uniform approach for the selection of ARFs used in consequence assessments based upon the degree of definition of the relevant parameters (i.e., the type and level of the suspension mechanism applied to the material-at-risk and the behavior of other materials and equipment that may affect the airborne release) and the complexity of the initiating event.

The criteria for selecting ARFs are presented in Section 3. Section 4 discusses the limitations of the standard. Background information on the analytical process commonly employed to calculate source terms is necessary to understand fully all aspects of the ARF selection process; sample problems illustrating the application of ARFs to some accident scenario analysis are also helpful.¹

2. Definitions

aerodynamic entrainment. The suspension and transport of particulate materials, initially at rest, by the flow of gas.

aerodynamic equivalent diameter (AED). The diameter of a sphere with a density of 1 g/cm^3 that exhibits the same terminal velocity as the particle of concern.

airborne release fraction (ARF). The fraction of affected material that can be suspended in air and become available for airborne transport.

airborne release rate (ARR). The fractional rate of affected material that is suspended into air and becomes available for transport as a function of time.

brittle solids. Solids that will fragment into particles upon impact or crush forces that exceed the tensile/compressive strength of the material.

energetic event. An event that generates a sufficient amount of energy over a brief period (such as less than one minute) to result in the airborne suspension of the material-at-risk, and damages equipment and systems that might result in loss of confinement.

free-fall spill. An elevated release of powder or liquid as a slug of material that falls without obstruction and impacts a hard, essentially unyielding surface.

material-at-risk (MAR). The amount of radioactive material available to be acted upon by the physical stresses generated by the accident conditions.

peer review. The review and concurrence of the basis and findings of a document or paper by more than one individual recognized as knowledgeable in the specific technical area.

respirable fraction (RF). The fraction of material made airborne, present in particulate form, that could be transported through the air, inhaled, and be deposited in the deep lung.

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

¹ Information on this topic is provided in Appendix B.

source term. The amount of radioactive material available for release from confinement if a leak were to occur at the confinement boundary.

surface contamination. Radioactive material on the surface of solid objects.

suspension mechanism. The type and level of force/energy input defined and utilized for analysis of a given postulated accident for the process or operation performed.

3. Criteria for Selection of Airborne Release Fractions

The principal factors that influence the amount of material released from confinement are described in the following paragraphs. These factors are the suspension mechanism applied to, and the physical forms of, the MAR. Selection of the ARFs shall be based upon these factors as well as the level of detail provided in the analysis. The selection process can include application of empirical correlations, models, and inferences from experiments.

3.1 Characterization of the Type and Level of Suspension Mechanism Imposed on the Material by the Initiating and Secondary Events. Identification, understanding, and evaluation of the mechanisms involved in the release of the material-of-concern shall be performed for the selection of the proper ARF for an event.² If the suspension mechanisms associated with the postulated event are standard phenomena (e.g., liquid sprays, free-fall spills of powders and liquids, aerodynamic entrainment), textbooks on the mechanisms/phenomena and previous analyses on the same or similar situations should be used as a model. The available information on the stresses and response of the material-of-concern to the stresses shall be documented in the basis for ARF selection.

3.2 Determination of the Level of Detail. The possible ARFs change as the level of detail and analysis performed to define the level of the suspension mechanism imposed. Some ARF values are only available as a single bounding value or in a general form due to paucity of experimental data. Other ARF values are available in general form with considerable detail, and lower ARF values may be identified if the level of definition

can support such a decision. If information is available, the ARF value can be selected with greater precision if a specific event definition exists. Theoretical values can be appropriate for simple phenomena. Models describing a phenomenon are appropriate for that specific phenomenon only and, thus, might not define the more complex phenomena occurring under accident conditions postulated.

Source term calculations are performed for a variety of purposes, ranging from hazard categorization of nuclear facilities to preliminary hazards analysis to Safety Analysis Reports (SARs) to probabilistic risk assessments. The accuracy achievable for each level of estimates varies with the level of definition of the accident scenario (behavior and response of the materials involved). The requirements for ARFs as a function of the level of definition provided for these relevant parameters are presented below.

3.2.1 Analyses Based on Scenarios with Characterization of Phenomenon. For conservative analyses, in which only the accident phenomena is known, the ARF shall be found by comparing the level of the suspending mechanism to those for similar phenomena summarized in published, reviewed documents.³ If the effect of the suspension mechanism on the material form is included in the documents, the bounding value shall be determined and documented.

If the suspending mechanism or the level of suspending mechanism is not included in the summary document, the ARF shall be found through the use of a bounding value in the summary document that is similar as possible or based upon engineering judgement.

In either case, the value chosen shall be documented and justified.

3.2.2 Analyses Based on Characterization of Bounding Event Parameters. For detailed analyses where use of generic conservative assumptions might be inappropriate, the type and

² Information on this topic is provided in Appendix B.

³ Refer to the following: DOE Handbook - Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities: Volume I - Analysis of Experimental Data; Volume II - Appendices, DOE-HDBK-3010-94, December 1994, U.S. Department of Energy, Washington, DC 20585; and NUREG/CR-6410, Nuclear Fuel Cycle Facility Accident Analysis Handbook, prepared by SAIC for the Office of Nuclear Materials Safety and Safeguards, March 1998, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

level of suspension mechanism shall be compared to experimental parameter information available for that type of stress. The ARF shall be determined from this information. ARF values chosen shall be consistent with the bases in published, reviewed documents,⁴ unless an alternative value can be selected based upon supporting documented, peer-reviewed, experimental data verifying the bases for such deviation. If characterization of the relevant parameters allows, ARF values may be interpolated to arrive at a lesser bounding ARF. A discussion of this issue for many experimental studies can be found in published documents.⁵

3.2.3 Analyses Based on a Well Characterized Sequence of Events. If the scenario description and analyses provide a more detailed characterization of the relevant parameters and correlates the ARF with the theoretical basis for the suspension mechanism, the ARF may be interpolated or extrapolated if the basis is documented, but in such a case it shall be demonstrated that discontinuities are not expected. If the suspension mechanism can not be determined, or applicable ARFs are not found in the existing data base or applicable experimental data found in the reviewed literature, "bounding values" shall be used, or experimental studies shall be performed, reviewed, and published to establish new values.

3.3 Selection of Specific ARF Value for Events. ARF values shall be based on technically sound, well documented, reviewed information that applies to the response of the physicochemical state of the material-of-concern to the specific type of suspension mechanism resulting in the airborne release. The choice of ARF shall bound the level of that stress postulated for the event.

The ideal values would be selected from a mechanistic model of the airborne release of the material-of-concern verified by experimental data over the entire range of concern. There are currently no such data. Values for ARFs selected from a mechanistic model with experimental verification over a limited range of stress bounding that postulated for the event would also be very desirable, but are not available.

⁴ A summary table of documented, peer-reviewed ARFs and RFs is provided in Appendix A.

⁵ DOE-HDBK-3010-94.

First principal models for some non-complex material behavior (e.g., venting of pressurized gas from containment, evaporation of liquids) are also applicable to well characterized phenomena and may be applied to events that can be demonstrated to be these phenomena.

Empirical correlations to experimental data over a limited range of the stress for physical forms of material (often for the specific material-of-concern) are available and shall be applied for all applicable cases.

Experimental data on the release of specific materials over a limited range, or a single value for the critical parameter, may be applied to estimate the airborne release of specific materials for situations where the estimated level of the critical parameter is bounded by the experimental data.

ARF values inferred from the experimentally measured response of a physically similar material subjected to the same type and bounding level of stress may be applied in the absence of more directly applicable values.

3.3.1 Materials Contained in the Gaseous State. All overpressure shall be assumed to be vented upon loss of containment/confinement.

3.3.2 Materials Volatilized by Initiating Event. The fraction of material-of-concern volatilized is dependent on the conditions resulting in conversion of material to the gaseous state, and shall be considered as eventually released. If documented, peer-reviewed experimental data supports reduction of the release due to chemical conversion or physical processes, the ARF may be reduced by a corresponding amount.

3.3.3 Volatile Liquids and Solids. Volatile materials will evaporate at a rate determined by material properties and ambient conditions. Without mitigation, eventually all material will be released. In the presence of the appropriate conditions resulting in evaporation of the material, an ARF of unity shall be assumed, unless reduced to a lesser value by appropriate, documented, peer-reviewed experimental data.

If the evaporation rate is of concern in the scenario, the ARR shall be determined based on the documented evaporation rate of the solid or liquid.

3.3.4 Non-Volatile Liquids and Solids. ARFs from documented, peer-reviewed, experi-

mentally-derived values shall be applied based upon the type and level of the suspension mechanism, the event conditions, and the level of definition of the relevant parameters. Materials in these physical states can be separated, suspended, and transported to the local flow field to become an inhalation hazard to the downwind population. Some of the categories of solids possessing characteristics that affect fragmentation and suspension are:

- elastic-plastic solids, such as metals;
- brittle solids, such as glass or aggregate; and,
- powders with various physical characteristics from homogeneous or heterogeneous beds; homogenous beds include the same or similar particles with a depth greater than two particle diameters thick, while heterogeneous beds include sparse deposits of particles covering the surface of a dissimilar material such as dust on a hard surface.

Each type of solid is most readily subdivided by different types of forces/stresses. Elastic-plastic materials are fragmented by stretching beyond their tensile strength or, for reactive metal, oxidized into another compound that forms particles. Brittle solids are most readily fragmented by crush-impact forces that exceed the tensile strength of the material. Force is necessary at the particle-to-particle interface to separate the individual particles, or clusters of particles, in powders. Suspension of surface contamination requires the separation of the contaminant from the bulk material or the suspension of the bulk material (the types of suspension mechanisms that fragment and suspend solids was covered in the second bulleted item above).

In some cases with liquids (e.g., aqueous solutions or suspensions), the material-of-concern is the solute, or the particulate material or materials suspended in the liquid. In these cases, suspension of the material-of-concern shall be considered subdivision of the bulk liquid (formation of droplets).

3.4 Comparisons with Previous Documented and Reviewed ARF Values. The ARF value selected shall be compared with information from previous or other analyses for the same or similar conditions to assure consistency and appropriate conservatism. Deviation from the published values shall be documented and supported either by published, peer-reviewed, experimental data, or by reasons provided to explain the deviations.

4. Limitations

All empirical correlations used to derive ARFs shall only be applicable within the range of experimental parameters, unless they are supported by documented experimental data that verifies the validity of the suspension mechanisms outside the range and establishes that discontinuities do not exist.

The ARFs shall be limited to the type of suspension mechanism imposed and the response of the material with the physical characteristics that results in the airborne release.

Due to the many uncertainties in the extension of experimental data, and the fact that much of the experimental data is based on exemplary rather than parametric experimental studies, the ARFs shall be limited to one significant figure, unless documented experimental data is available to support the use of more than one significant figure.

Uncertainties associated with the estimate of the airborne release are very difficult to estimate and can be misleading. The airborne release calculation shall consider the independence and interrelated parameters such as:

- The actual level of stress generated by the initiating event.
- The response of all materials to the level of stress applied at the specific location postulated in the event (the actual level of stress applied to the material-of-concern may depend upon the attenuation or enhancement of the level of stress generated by intervening materials).
- The impact of secondary stresses generated by the responses of other materials involved [e.g., debris generated by the initiating event (including fragments and missiles); other energetic events initiated, such as fire, explosion, or chemical reactions].
- How much of the material-of-concern is actually impacted by the stress (shielding from direct impact of stress of all or part of the material-of-concern by barriers or obstructions).
- The presence or absence of barriers or obstructions to release.

Thus, the probability of any specific response may vary widely. The use of statistics can result in improper evaluations of the uncertainty. If the