# U. S. REACTOR CONTAINMENT TECHNOLOGY

A COMPILATION OF CURRENT PRACTICE
IN ANALYSIS, DESIGN, CONSTRUCTION,
TEST, AND OPERATION

# VOL. I

Wm. B. Cottrell and A. W. Savolainen
Editors

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## A Compilation of Current Practice in Analysis, Design, Construction, Test, and Operation

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Prepared by Oak Ridge National Laboratory
and Bechtel Corporation

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# FOREWORD

As a consequence of preparation of the quarterly technical progress review Nuclear Safety, it became apparent both to the Oak Ridge National Laboratory editorial staff and to cognizant persons in the AEC Division of Reactor Development that there existed a wealth of uncorrelated information on the subject of reactor containment. Accordingly, in the fall of 1962, the Laboratory was authorized to undertake the present compilation, which was essentially completed in its present form in the spring of 1964.

In an effort to make the compilation as comprehensive and as authoritative as practical, the Laboratory subcontracted the responsibility for preparation of four of the 12 chapters (i.e., Chapters 8, 9, 10, and 11) to Bechtel Corporation, a major architect-engineer and fabricator of reactor containment structures. The authorship of the remaining chapters was then assigned to senior Laboratory personnel, supplemented in many instances by experts from other installations. Thus in addition to the literally hundreds of persons who reviewed the various drafts, numerous persons have made substantial original contributions to this work. Although these persons and the extent of their contribution are indicated at the beginning of each chapter, they are all listed alphabetically below in order that we may collectively acknowledge their contributions.

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Of the many persons listed above, both within and without the Laboratory, we would like to express particular thanks to M. I. Lundin, who coordinated the Bechtel Corporation subcontract, and to H. B. Piper who, in addition to his contributions as an author, coordinated the review of all the chapters and prepared the index.

In order to make the greatest possible use of this compilation, readers should familiarize themselves with Chapter 1, which, in addition to providing essential background material, contains a section specifically designated "Guide to the Use of this Report." In addition, an extensive index is available.

It will be appreciated that a compilation of this type - particularly the first of its kind - on a relatively new subject and one upon which there is considerable research and development will be subject to frequent evaluation and change, at least until a much higher plateau of knowledge and experience is attained. Thus the editors are aware of the limited timeliness of the material herein and anticipate, circumstances permitting, that the material will be revised every two or three years. Toward that end, this document is being distributed in a loose-leaf binder, and recipients wishing to receive revisions of this material are asked to advise the editor of any changes in address.

The editors also wish to acknowledge the support, encouragement, and constructive criticism of the sponsors within the AEC Division of Reactor Development, particularly J. A. Lieberman, Assistant Director for Nuclear Safety; S. A. Szawlewicz, Chief, Research and Development Branch; and R. N. Newton, Research and Development Branch, without whom this work would not have been possible. However, the reader is cautioned not to regard the inclusion of any information here as giving that information any official sanction as far as the AEC Division of Compliance or Division of Reactor Licensing is concerned. This report does no more than reflect the current state of the art to the satisfaction of the Oak Ridge National Laboratory and the Bechtel Corporation. Furthermore, it cannot anticipate what changes in containment technology may evolve from research and development or the official attitudes regarding the adequacy of containment provisions for a particular application that may evolve from the continuing deliberation of either the Advisory Committee on Reactor Safeguards or the Division of Reactor Licensing.

Editors
Wm. B. Cottrell
A. W. Savolainen

# PREFACE

Although this report was not prepared by or under the auspices of the Nuclear Safety Information Center, it is being distributed as an NSIC report for the following reasons: (1) containment is one of the most important interests of the NSIC and (2) the NSIC can provide the continuity, as well as the source material, for future revisions. The Nuclear Safety Information Center was established in March 1963 at the Oak Ridge National Laboratory under the sponsorship of the U.S. Atomic Energy Commission. The Center serves as a focal point for the collection, storage, evaluation, and dissemination of information in the following areas:

Containment of nuclear facilities
Fission-product release, transport, and removal
Nuclear instrumentation, control, and safety systems
Radioactive effluent control monitoring, movement, and dosage
Reactor transients, kinetics, and stability
Meteorological considerations
Operational safety and experience

In addition to state-of-the-art reports in the above subject areas, the Center prepares the quarterly technical progress review Nuclear Safety and has a reference file stored on magnetic tape for the computer search of safety information and the preparation of a quarterly indexed bibliography of the nuclear safety literature.

Inquiries concerning the services, capabilities, and operation of the Center should be addressed to:

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# GUIDE TO THE USE OF THIS REPORT

## Purpose

In order to make use of the information that may be found in this report, not only should the specific purposes be known but also the subjects that are excluded. For the purposes to stand out clearly, it is pertinent to note that this report does not propose to

1. evaluate the safety of specific systems for specific applications,
2. present information on the design, integrity, or performance of the primary system,
3. discuss extensively the behavior of fission products after leaving the reactor-containment system (see Sec. 4.5.1),
4. establish criteria by which containment systems must be designed, fabricated, tested, and operated.

On the other hand, it is the purpose of this report to

1. describe the containment features of existing reactor installations,
2. describe some of the calculational techniques that have been employed to determine fluid dynamics and radiological loads on containment systems,
3. present experimental data pertinent to items 1 and 2,
4. describe pertinent details of the design, construction, and test of containment systems,
5. present existing data on the cost of containment systems,
6. review the current research and development pertinent to the above items.

Pertinent matters of significant interest to the containment designer and fabricator or to the plant operator concerning the containment system have been considered in this report. Thus it is concerned not only with the design of the many existing containment systems but also with how and why these designs were developed and why particular containment systems appear more suitable in certain reactor systems for certain applications. The capabilities and limitations of the various containment systems and also the accidents for which the containment is provided are discussed. The existing regulatory requirements that must be met at a particular place and time are cited. Unfortunately, none of these requirements are fixed and it is not possible to speak in absolute terms except with regard to what has been done. The information presented provides a point of departure for more advanced designs, improved engineered safeguards, and possibly even changes in the siting requirements.

Chapters 2 through 6 set forth the salient basic information regarding containment requirements for particular reactors and sites. Chapter 2 gives the pertinent regulations and existing criteria. Chapter 3 discusses the nature and scope of the accidents that are examined for every reactor in order to identify the accident that is considered the maximum credible for that reactor and which in turn determines the containment requirements. Chapter 4 gives the amounts and nature of the fission products that must be contained. Chapter 5 discusses the energy that the containment system must be designed to cope with. Chapter 6 gives a summary of the special

analytical techniques frequently involved in containment analyses. Chapter 7 describes existing containment systems; Chapter 8 gives design considerations; Chapter 9 describes auxiliary components; and Chapter 10 lists the performance tests required. In Chapter 11 the identifiable costs associated with various containment systems and parts thereof are tabulated. Chapter 12 presents a resume of current research pertinent to all aspects of containment.

## Limitations and Use

At the present stage in the development of both reactor and containment technology, it is not possible to develop a definitive relationship between reactor type, power level, and containment system that can be employed to identify the most economical containment system for use with a given reactor installation. Examination of the trends discussed here, as well as considerations of the obvious points of compatibility and incompatibility between various reactor and containment types, will, however, point to combinations of interest. The cost information in Chapter 11 is of limited value because of the uncertainty in the cost accounts that were available, the apparent wide range in costs for similar systems, and the many subtle differences in superficially similar reactor installations. Trends do become evident with data presented here, although these trends may have been apparent anyway. The most pertinent advice that can be offered regarding costs of different containment systems for a given application is that, assuming no obvious mismatch (see Table 1.12) and that the safety provided by each is acceptable to the regulatory authorities, the best containment system (i.e., the least expensive) must be determined from a cost analysis of a fairly detailed design of two and sometimes more arrangements.

It should also be appreciated that most of the containment information reported here has been derived from a reactor technology that has been and still is oriented toward a water-cooled and -moderated reactor. It is not surprising that starting with this background, the containment systems provided for other types of reactor are adaptations of, and subject to, much of the same rationale as those that developed out of the technology of water-cooled power reactors. It is quite conceivable that starting from another frame of reference, for example, the gas-cooled graphite-moderated reactors, which form the basis of the United Kingdom nuclear power program, the accepted containment systems might have been considerably different. It is also possible that they might have afforded comparable protection.

The containment analyst is also cautioned against regarding the criteria and designs described here as being fixed. The past several years have witnessed many innovations in containment design, increasing expenditures in containment research and development, and the establishment of the first reactor siting criteria. The present rapid pace in the development of containment technology cannot help but have significant ramifications in containment design and criteria.

The reader is also cautioned not to regard the inclusion of any information here as giving that information any official sanction as far as the AEC Divisions of Compliance or Reactor Licensing are concerned. Even in

instances where members of these AEC regulatory divisions may have received or supplied material for use herein, that does not per se establish that material or any other portion of this report as an official regulation, standard, or criterion that must be followed in the analyses, design, construction, testing, or operation of a containment system. This report does, however, attempt to include all relevant information and in so doing includes many criteria that are frequently associated with containment systems, some of which have been approved for specific sites and specific reactors.

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