GUIDELINES FOR PRESSURE RELIEF AND EFFLUENT HANDLING SYSTEMS

with website

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SECOND EDITION

CCPS
An AIChE Technology Alliance
Center for Chemical Process Safety

DIERS

WILEY

GUIDELINES FOR

PRESSURE RELIEF AND EFFLUENT HANDLING SYSTEMS

This book is one in a series of process safety guideline and concept books published by the Center for Chemical Process Safety (CCPS) in cooperation with the Design Institute for Emergency Relief Systems (DIERS). Please go to www.wiley.com/ccps for a full list of titles in this series.

DISCLAIMER

GUIDELINES FOR

PRESSURE RELIEF AND EFFLUENT HANDLING SYSTEMS

SECOND EDITION

CENTER FOR CHEMICAL PROCESS SAFETY

of the

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DEDICATIONS

Dr. Michael A. Grolmes (Centaurus Technology), an original employee of Fauske & Associates LLC, who was principally responsible for development and documentation of much of the DIERS two-flow technology, the large-scale blowdown and reactive experimental program, and the SAFIRE computer program.

Dr. Joseph C. Leung (LeungInc), an original employee of Fauske & Associates LLC, who was jointly responsible for development of the DIERS Bench-Scale Apparatus (Later the VSP) and the reported experimental results as well as development of the Omega Method for calculating two-phase flows and sizing emergency relief systems for runaway reactions.

Dr. Georges A. Melhem (President and CEO, ioMosaic Corporation) who developed the SuperChems™ family (EXPERT, DIERS, and Lite) of computer programs. These programs are widely used for various process safety studies and sizing of emergency relief and flare systems. The SuperChems™ for DIERS computer program was made available for licensing and distribution by AIChE. The SuperChems™ for DIERS Lite computer program was made available to AIChE for distribution and licensing with this book. Dr. Melhem was co-editor of this guideline and the 1st (1995), 2nd (1998) and 3rd (2005) International Symposium Proceedings published by AIChE / DIERS.

ioMosaic Corporation provided editorial, administrative, and significant financial support for the publication of this guideline and the 1st (1995), 2nd (1998) and 3rd (2005) International Symposium Proceedings published by AIChE / DIERS.

Fauske & Associates LLC, led by Dr. Hans K. Fauske, was the DIERS contractor responsible for the original development and documentation of the DIERS technology that changed the engineering paradigm for design of emergency relief system involving runaway reaction and two-phase flow. FAI recently celebrated their 35th anniversary of continuous technology development and support of safety improvements for the chemical process and nuclear industries.

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PREFACE

The American Institute of Chemical Engineers (AIChE) has been closely involved with process safety and loss control issues in the chemical and allied industries for more than four decades. Through its strong ties with process designers, constructors, operators, safety professionals, and members in academia, AIChE had enhanced communication and fostered continuous improvement of the industry's high safety standards. AIChE publications and symposia have become information resources for those devoted to understanding the causes of incidents and discovering better means of preventing their occurrence and mitigating their consequences.

The Design Institute for Emergency Relief Systems (DIERS), formed in 1976, was a consortium of 29 companies that developed methods for the design of emergency relief systems to handle runaway reactions. DIERS spent $1.6 million to investigate the two-phase vapor-liquid onset / disengagement dynamics and the hydrodynamics of emergency relief systems. Of particular interest to DIERS were the prediction of two-phase flow venting and the applicability of various sizing methods for two-phase vapor-liquid flashing flow.

DIERS became a Users Group in 1985 with a purpose:

- to reduce the frequency, severity and consequences of pressure-producing accidents and
- to promote the development of new techniques that will improve the design of emergency relief systems

The DIERS Users Group conducted 60 semi-annual 3-day technical meetings in 31 cities to include three International Symposia, three meetings in Canada, and two Joint US – European DIERS meetings in Hamburg and Dü sseldorf, Germany during the last 30 years. There were nineteen visits to industrial (chemical production plants; safety relief valve, rupture disk, and breather vent manufacturing facilities; and equipment supplier laboratories) and twelve computer and laboratory equipment training sessions conducted in conjunction with the semi-annual technical meetings. Approximately 625 additional technical presentations have provided a learning environment for the company representatives.

A combination of computational and / or experimental round-robin exercises have been conducted almost every year since the formation of the DIERS Users Group.

The reorganization of DIERS in 2015 from a corporate based to an individual based membership will provide a basis for further growth. New general (non-funded) and special (funded) projects as well other initiatives and activities are planned and underway to increase the scope and breadth of DIERS technical and outreach programs.

The Center for Chemical Process Safety (CCPS) was established in 1985 by AIChE to develop and disseminate technical information for use in the prevention of major chemical incidents. CCPS is supported by more than 170 sponsoring companies in the chemical process industry and allied industries; these companies provide the necessary funding and professional experience for its technical subcommittees.

Pressure relief systems have always been important components in the design of safety systems for chemical and petrochemical plants. The first DIERS book on pressure relief systems was *Emergency Relief System Design Using DIERS Technology: The Design Institute for Emergency Relief Systems (DIERS) Project Manual* (CCPS 1993). The first edition of *Guidelines for Pressure Relief and Effluent Handling Systems* was issued in 1998 in recognition of the need for guidance in designing emergency relief systems to minimize or contain the discharge of potentially harmful materials. This second edition has been written to incorporate learnings in the field of emergency pressure relief since then.

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IN MEMORIAM

To the Memory of Our Colleagues

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FILES ON THE WEB ACCOMPANYING THIS BOOK

Access the *Guidelines for Pressure Relief and Effluent Handling Systems, Second Edition,* software and documents using a web browser at:

http://www.aiche.org/ccps/PRTools

Each folder will have a readme file and installation instructions for the program.
After downloading SuperChems™ for DIERS Lite, the purchaser of this book must contact ioMosaic with the numeric code supplied within the sealed packet in this book. The customer support line at ioMosaic for these programs is **603-685-6944**. The purchaser will then be supplied with a license code to be able to install and run SuperChems™ for DIERS Lite. Only one license per purchaser will be issued. Once the sealed packet is broken and code uncovered, book cannot be returned.

These programs are offered as is, with no guarantee. The disclaimer in this book applies to the software, as well as the contents of the book.

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INTRODUCTION

1.1 OBJECTIVE

Guidance for the design and selection of pressure relief devices for most applications can be found in documents provided by several organizations including: the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), the National Fire Protection Association (NFPA), the Compressed Gas Association (CGA), and the International Organization for Standardization (ISO). The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) regulation and the similar Environmental Protection Agency (EPA) Chemical Accident Prevention regulation (commonly referred to as Risk Management Plan (RMP)) and increased industry efforts to improve safety and environmental protection practices have led to much greater focus on reducing and controlling releases of materials from pressure relief systems to the atmosphere.

The guidance and sizing formulas provided by the above organizations are generally applicable only to single-phase flow. Research and studies by the Design Institute for Emergency Relief Systems (DIERS) resulted in a new body of technology on two-phase flow from relieving vessels and the effect of two-phase flow on pressure relief system design and on the performance of pressure relief valves under such conditions. These developments suggested a need for a presentation from a chemical industry perspective on the design and selection of pressure relief devices for single as well as multi-phase flow from pressure relief systems and for the treatment of the effluent from pressure relief systems. Preparation of this book by the CCPS was in response to this need.

This CCPS / DIERS book is directed toward experienced process engineers and specialists with a basic proficiency in fluid dynamics and process engineering fundamentals. The objective is to present information that will provide guidance for selecting and designing reliable emergency pressure relief and effluent handling systems. These systems should be designed to protect equipment from overpressure and to either contain or safely control hazardous materials discharged during an emergency.

This second edition presents updated information on several widely used national codes and standards to include those which have been adopted by regulatory authorities for inclusion in either federal or local regulations. These documents should be viewed by designers as representing industry practices with proven value in providing reliable process safety systems, not just as regulations requiring compliance.

1.2 SCOPE

General background information on pressure relief technology is presented along with guidance for selecting relief devices and effluent handling equipment. Calculation procedures for designing pressure relief and selected effluent handling equipment are also presented. Numerous example problems are used to illustrate calculation procedures. Computer programs are presented for handling flow calculations for compressible gases, for evaluating complex two-phase flow situations, and for sizing effluent handling equipment. The book includes:

- Discussions of national and international codes and regulatory impacts on pressure relief system design and operation.
- Reviews of causes of overpressure events and selection of the worst case scenario and the relief system design and design basis for the relief system including systems involving chemically reactive and highly viscous materials.
- Descriptions of a range of relief devices and operating performance characteristics including flow calculation methods for sizing pressure relief devices and associated piping systems.
- Characterization of fluid properties including sources of property information and handling of mixtures.
- Methods for calculation of reaction thrust forces from discharge of relief systems.
- Guidance in selecting effluent handling systems including equipment commonly used for pressure relief system applications. This includes gravity and cyclone separators, scrubbers, quench pools, flares, and atmospheric dispersion (for non-hazardous materials only).
- Calculation procedures for sizing the most widely used equipment for effluent handling, including gravity separators, cyclones, quench pools and spargers.

Maintenance, operations, and testing procedures and technology are not discussed in detail, but are covered briefly in selected cases. Prevention or mitigation of overpressure incidents and the essential components of a good process safety management system are beyond the scope of this book. Such procedures and technology include emergency control or shutdown systems, inherent safety concepts, safety layers of protection, prevention of explosive deflagrations and detonations, and other measures used to reduce the frequency or magnitude of emergency overpressure events. Guidance on these subjects can be found in other CCPS books, which are listed in the appropriate sections of this book.

If potentially hazardous materials might be discharged to the atmosphere, specialists on the health and environmental effects should be consulted to determine safe levels of discharge to the air, water, and land. In general the release of hazardous materials to the environment should be avoided if at all possible.

1.3 DESIGN CODES AND REGULATIONS, AND SOURCES OF INFORMATION

There are a number of organizations that provide information on pressure relief and handling of effluent from pressure relief systems. Some of these, with a brief summary of their role, are shown below (see Section 2.3.1 for a more extensive listing):

Federal and local governments. The federal government, through OSHA and EPA regulations, provides much information on requirements for process safety and environmental protection. Many states have implemented regulations that parallel or exceed federal regulations. Designers and operators of pressure relief systems should maintain a familiarity with these requirements. While the focus in this book is on practices, codes, and standards of U.S. origin, designers and operators of facilities in other countries are urged to become familiar with any practices or regulations that may apply. In many cases facilities designed to meet U.S. requirements will either meet or exceed requirements based on international regulations.

American Society of Mechanical Engineers (ASME). The ASME publishes the Boiler and Pressure Vessel Code (ASME BPV Code), which contains basic requirements for overpressure protection of vessels covered by the Code. Section VIII covers Pressure Vessels, which are applicable to the petroleum and chemical process industries. Many governmental authorities have adopted the ASME BPV Code and made it part of their regulations. The ASME BPV Code therefore has the force of law in many states.

American Petroleum Institute (API). The API publishes a series of standards and recommended practices that cover the fundamentals and application of pressure relief technology including pressure relief of low pressure tanks and testing and maintance of pressure relief valves. Many recommendations are presented that cover various aspects of pressure relief system design, including effluent handling.

National Fire Protection Association (NFPA). The NFPA publishes a number of documents that present pressure relief requirements for various specific fluid services. Their Flammable and Combustible Liquids Code (NFPA 30), Standard for Water Spray Fixed Systems for Fire Protection (NFPA 15), Standard on Explosion Protection by Deflagration Venting (NFPA 68) and Standard on Explosion Prevention Systems (NFPA 69) are of particular interest to the chemical and petroleum process industries.

National Board of Boiler and Pressure Vessel Inspectors (NB). The National Board publishes information on certified flow capacity of valves tested in accordance with ASME procedures and documents related to inspection and repair of pressure relief valves.

International Organization for Standardization (ISO). ISO publishes international standards. Some of these documents are cross-branded with API documents. Compliance with these standards is required by most European countries. The ISO 4126 standard for safety devices for protection against excessive pressure is divided into eleven separate parts applicable to safety valves, rupture disks, pilot operated valves and other topics.

DIERS. The Design Institute for Emergency Relief Systems (DIERS) was established in 1976 to develop a better understanding of pressure relief system technology including vapor-liquid disengagement in vessels and flow of two-phase fluids through pressure relief devices and piping. The results of the initial research have been published (DIERS 1992). Current developments are covered during DIERS biannual meetings and in associated reports where information on new research, practices and technology is presented and discussed.

Other sources of information that supplement the standards and codes indicated above are given as references and noted within the text of each chapter of the book.

1.4 ORGANIZATION OF THIS BOOK

Pressure relief technology is covered in the chapters of this book. The following is a brief summary of each chapter:

Chapter 1. Introduction

Chapter 2. Relief System Design Criteria and Strategy: Presents general information on pressure relief technology (including terminology and definitions) pressure relief design strategies, ASME BPV Code requirements, and descriptions and layout of relief systems. Also covered are causes of overpressure, review of worst credible relief scenarios, analysis of vapor-liquid phase behavior in vessels, determination of required flow capacity, fluid properties and system characterization, flow of fluids through relief systems, and relief system reliability.

Chapter 3. Requirements for Relief Systems Design: Covers vessel venting background to include vessel onset / disengagement dynamics for evaluating whether two-phase flow might occur, venting requirements for nonreacting cases, calorimetry for reactive emergency relief system design, and venting requirements for reactive cases.

Chapter 4. Methods for Relief Systems Design: Covers calculation methods for sizing and rating pressure relief devices and associated piping to include computerized and manual methods for safety relief valves and piping and rupture disks and associated piping for vapor, liquid, and two-phase flows.

Chapter 5. Additional Considerations for Relief Systems Design: Covers the mechanical forces involved during emergency venting. Methods for estimating reaction thrust from relief system discharge are covered.

Chapter 6. Handling Emergency Relief Effluents: Presents guides to selection of equipment and systems to treat the effluent from relief devices. The focus is on equipment and techniques that are more commonly used in pressure relief applications. Information is summarized in tables that list advantages, disadvantages, and areas of possible application for the various types of equipment.

Chapter 7. Design Methods for Handling Effluent from Emergency Relief Systems: Covers design methods and sizing calculation procedures for various types of equipment and processes that are commonly used to treat effluent in emergency relief situations. Methods are presented in detail for gravity separators, cyclone separators, and quench pools (including spargers for quench pools).

Computer Programs. Several useful computer programs are provided at the CCPS website listed in the front of the book. These programs are provided to aid in making flow calculations for relief devices and piping and for sizing selected effluent handling equipment. The computer programs include the SuperChems™ family of new programs and the CCFlow and TPHEM legacy programs provided in the first edition of this guideline.

SuperChems™ for DIERS Lite includes steady state methods for evaluation of relief requirements and contains a visual interface for the construction of piping isometrics with a variety of pressure relief devices components such as rupture disks and safety relief valves. SuperChems™ for DIERS includes methods for modeling the dynamics of relief from vessels with and/or without chemical reactions.

The CCFlow family of programs includes the following:

- TPHEM, a DOS program for two-phase flow through piping and nozzles,
- COMFLOW, a DOS program for gas/vapor flow through piping and nozzles,
- CCFlow, a Windows ® program for two-phase and gas/vapor flow through piping and nozzles for sizing and evaluating relief valves and for sizing gravity separators, cyclone separators, and spargers.
- CCFlow Utilities, a program to calculate Antoine coefficients, compressibility factors, and isentropic expansion coefficients. Multicomponent systems can be handled for the latter two items.

Instructions for use of The CCFlow program are included in the CCFlow Help files. The uses of the programs are illustrated in the Appendices. These programs do not address determination of required relieving capacity or composition of the effluent.

1.5 GENERAL PRESSURE AND RELIEF SYSTEM DESIGN CRITERIA

Anyone with responsibility for designing, operating, and maintaining pressure relief systems and other process equipment should be familiar with: the provisions of the OSHA Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119) PSM standard; the EPA Risk Management Program (40 CFR 68.130) RMP rule; and the requirements of States that have their own State Plan. Guidance on the implementation of the principles embodied in the Federal and State standards are discussed in general in CCPS (1989c and 1992) and in API Standard 750. More specific guidance on each of the required elements is provided in numerous CCPS books.

While compliance with all applicable regulations is important, the basic objective is the safety of people and preventing damage to facilities and the environment. Compliance with regulations alone may not provide an acceptable level of protection. Compliance with the Federal and State Plan regulations is required if a listed chemical is present in the process in an amount equal to or in excess of a threshold quantity. The engineering practices provided in this book are applicable to all processes and may be considered to represent the current best thinking of the DIERS working group.

Company standards and practices are also an important source of information on design requirements for pressure relief systems. They are usually based on process safety management principles that have been developed from many years of experience. Many regulations use industry best-practices as a reference. These practices have been proven to represent good business practices as well as good process safety management and have been incorporated into the culture of many organizations.

Some important process safety management techniques related to pressure relief system design, which are not covered in detail in this book, are discussed briefly below. OSHA published a standard in 1992, Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119) to control chemical hazards in the workplace. That standard covers basic requirements for implementing a good process safety management program which involves applying generally recognized and accepted good engineering practices to ensure process safety in new and existing plant facilities. Two components of a process safety management program referred to in 29 CFR 1910.119 are particularly relevant to the design, operation, and maintenance of pressure relief systems; these are Process Hazards Analysis and Process Safety Information, which are discussed briefly in the following sections.

1.5.1 Process Hazard Analysis

A chemical process and plant facility should be analyzed for all possible causes of overpressure to determine the worst credible scenario. The worst credible scenario establishes the design basis for the pressure relief and for the effluent handling system. Methods for conducting such a hazards analysis and evaluation are presented in CCPS (2003 and 2008a). The hazard analysis should be revalidated on a regular basis to review the current process conditions, any possible mechanical changes in the facility since the original construction or last hazard analysis, and maintenance and operating records for any signs of problems. The pressure relief system should then be verified to ensure that it is still adequate to protect the equipment. Guidance on how to revalidate a hazard analysis is provided in CCPS (2001) and by Chadwell (1997).

Inherent safety concepts should be applied during the process design on the hazards of the process. Refer to CCPS (2009) for guidance on this topic. This can include changing process chemistry to use less hazardous materials, avoiding extreme temperatures and pressures, and designing for total containment by increasing vessel design pressure.

Operating and maintenance personnel should be trained. Operating and maintenance procedures must be written for start-up, shutdown, upset, and normal operating conditions. These written procedures must be updated and must be part of the periodic hazard review and analysis program. Proper supervisory controls must be instituted and training and refresher courses provided for operating and maintenance personnel. Refer to CCPS (1989c, 1995e and 1996b) for guidance on this topic.

Process safety audits should be conducted. An independent audit and verification of the design can provide additional assurance that the emergency relief system will adequately protect the vessel. An audit of the initial design can include a review of overpressure events that were considered in selecting the design basis. A check of the final mechanical design and specifications for the pressure relief system should also reviewed. For existing process units, a periodic audit can include a review of current process conditions, any possible mechanical changes in the facility since the original construction, maintenance and operating records for any signs of problems, and verification that the pressure relief system is still adequate to protect the vessel. See CCPS (2008).