

Editors' Preface

In the autumn of 1983, a full-scale nuclear power plant control room simulator went into operation at the Institute for Energy Technology (IFE) in Halden, Norway. The simulator, combining full-scope plant models with configurable equipment, was a highly anticipated research tool for human factors research in the OECD Halden Reactor Project (HRP).¹ HRP is a research programme under the auspices of the OECD Nuclear Energy Agency. It is sponsored by a group of national organizations, representing nuclear power plant regulators, utilities, suppliers, and research institutions. IFE has hosted the HRP since its inception in 1958.

The Three Mile Island (TMI) accident in 1979 was an important driver for establishing a control-room simulator. The accident resulted in a partial meltdown of the reactor core. Analysis of the accident highlighted the critical role of human operators in ensuring plant safety. In recognition of the need to better understand operator performance in nuclear power plant control rooms, the new facility was named *Halden Man Machine Laboratory* (HAMMLAB). Twenty-five years after the first simulator went into operation, the laboratory comprises three full-scale nuclear power plant control room simulators, each representing a particular reactor design. The facilities for studying operator performance were extended over the years. The simulators in HAMMLAB can now be connected to virtual reality models of the physical parts of the plant. This allows running scenarios where control room operators collaborate with field operators working on plant components.

Since its inception, HAMMLAB has been at the heart of human factors research at the OECD HRP. The research topics addressed in HAMMLAB are driven by user needs, as identified by the HRP member organizations. The purpose of HAMMLAB studies is to generate knowledge for solving current and future challenges in nuclear power plant operation. In most cases, the studies fall under the broad umbrella of applied research. Traditionally HAMMLAB studies have

¹ In this book, HRP and Halden Project are used interchangeably.

been experimental in nature. In HAMMLAB, it is possible to study events as they unfold in realtime under partially controlled conditions² and in a highly realistic operational environment. A wide range of human factors issues, which would be impossible or highly impracticable to study in real-life settings, can thus be addressed in HAMMLAB. The question of how to perform experimental research in this setting has been continually addressed by the HRP, and the research methodologies have been continually adapted and innovated. HAMMLAB studies contribute to uncovering potentials and limitations of control-room operators as they work with different types of human-machine interfaces, different type of decision supports, different teamwork requirements, and in different operational states. The outcomes of these studies have been used to support design and assessment of nuclear power plant control rooms. These control rooms will better support human operators in performing safely and resiliently. Insights from these studies can be generalized to support safe operation in related industries.

This book celebrates the 25th anniversary of HAMMLAB. It presents selected studies from the period that immediately preceded the establishment of HAMMLAB to the time of its anniversary in 2008. The studies described in this book include representative examples of HAMMLAB research topics, but also examples of some of the more unique topics that have been addressed. We have strived to include a set of studies that jointly will convey an impression of the knowledge HAMMLAB studies have generated across the life-time of the laboratory—and more generally the type of knowledge that may be obtained from this type of studies.

The book is structured in five parts: introduction, perspectives on simulator studies, early simulator studies in HAMMLAB, recent simulator studies in HAMMLAB, and outlook.

The first part, *Introduction*, comprises two chapters which provide background information about conducting human factors studies in control-room simulators—both in general and in the context of HAMMLAB. [Chapter 1](#) introduces control-room simulators as research tools for human factors research in the nuclear power plant community. It describes the concept *simulator*, contrasts the roles of training and research simulators, and discusses what type of research questions can be addressed in control-room simulators. [Chapter 2](#) is an account of the history of HAMMLAB. It first gives a short account of the events leading up to the construction of the *Halden Boiling Water Reactor* (HBWR), and the establishment of the HRP. This is followed by a description of activities in the pre-HAMMLAB period and the major drivers for building HAMMLAB. The main body of the chapter provides the reader with an overview of activities performed in HAMMLAB across 25 years.

The second part, *Perspectives on simulator studies*, comprises four chapters, which each provide a unique perspective on simulator-based human factors research in HAMMLAB. [Chapter 3](#) describes the purpose of human factors research in HAMMLAB, and outlines the theoretical basis for performing

² In the sense the scenarios that the operators meet are pre-defined.

experimental research. It then suggests a position on future methodologies in HAMMLAB. [Chapter 4](#) accounts for how classical experimental methods have to be adjusted and expanded to serve simulator studies in HAMMLAB. The chapter provides insights on experimental design and human performance measurements and on the continual methodological development in HAMMLAB. [Chapter 5](#) raises the question of whether simulator studies really are the *next best thing* after studies of real work settings, as was claimed when HAMMLAB was established. The chapter provides a brief history of simulator studies in human factors research, identifies the changing conditions for human factors research, and concludes that methods and models should change when the nature of work and the practical problems changes. [Chapter 6](#) focuses on the tremendous functional capability of new technology and its ability to display information, and raise the question of how to decide which approaches to information system design to use in control rooms. The chapter proposes an approach to evaluating novel human–system interfaces in NPPs and other complex human–machine systems in the context of human factors and plant safety performance.

The main part of the book contains twelve chapters organized under the headlines *Simulator studies in HAMMLAB: Early studies* (third part) and *Simulator studies in HAMMLAB: Recent studies* (fourth part). Three of the chapters are organised under the heading *early studies*. These chapters describe studies performed both prior to and within HAMMLAB. The studies described are diverse, but each provides important knowledge about human factors issues, as well as insights into how human factors research related to NPPs was performed early on. The remaining nine chapters are organized under the heading *recent studies*.

The first chapter under the headline *early studies* is [Chapter 7](#). It describes the studies performed within the OPCOM project. OPCOM was a computerized, screen-based control room that was coupled directly to the HBWR in parallel with the conventional control room. The purpose was to study how to best present information to the operators in computerized displays, and also to demonstrate that it was possible to use computers to supervise and control a complex process. [Chapter 8](#) describes a series of studies on *mixed instrumentation*—a concept referring to control rooms that comprise a mixture of computerized and conventional instrumentation. These studies were carried out between 1985 and 1987. The chapter is rounded off by relating the findings in terms of mixed instrumentations from the 1980s to the situation today, using a recent project on the Leningrad Nuclear Power Plant as an example. [Chapter 9](#) describes the project Integrated Surveillance and Control System (ISACS), which was started in 1987. The ambition of the project was to demonstrate that an advanced, fully computerized control room where the operator was supported by computerized systems was feasible with respect to safety and efficiency. Compared to earlier work in the 1980s, where support systems were developed and tested separately, ISACS integrated all support systems available and presented a unified interface to the operator, which resulted in a highly automated system.

With the next chapter we move into part four *recent studies*. Alarm systems have been a major concern within complex industrial processes for many years.

In any control room, alarm indications are installed to present particularly important information to the operators about process deviations, plant disturbances and critical plant conditions. [Chapter 10](#) provides an overview of computer-based alarm system concepts, which have been developed and tested in HAMMLAB since 1983. The chapter offers a short summary of each alarm concept and the associated findings from HAMMLAB studies. During the 25 years of operation of HAMMLAB, significant efforts have been placed in developing and testing information displays to find out how to best present plant information to the control room crews. [Chapter 11](#) describes three attempts at superseding the traditional process mimic display. The design concepts are called task-based, ecological and function-oriented displays. The main characteristics of each design concept are presented, and the rationale for expecting performance improvements over traditional displays is explained. Technological innovations and the increasing role of automation in advanced systems raise questions about the role of the human operator and the number of humans required to run these systems. [Chapter 12](#) discusses a variety of approaches to evaluating staffing requirements. It describes in detail two HAMMLAB studies performed to evaluate staffing requirements in advanced versus conventional nuclear power plant control rooms. This chapter also illustrates how simulator data is used to construct human performance models.

Procedures are a central part of the safe operation of nuclear power plants. Designers of new builds and upgrade projects have to decide whether to implement procedures in computers. In HAMMLAB, research on computerized procedures has been ongoing since the early 1980s, and [Chapter 13](#) gives a historical account of some of this research. Some aspects about the tools for computerized procedures are described, and the chapter sums up two HAMMLAB studies as well as several studies on prototypes in Korea. [Chapter 14](#) presents four HAMMLAB studies investigating research questions about the interaction between nuclear power plant operators and high-level automatic systems. The studies suggest that explicit representation of the automatic system's activity in the human-system interface, and the use of verbal feedback from the automatic system on its activities, facilitate operators' ability to work efficiently with high-level automatic systems. The studies, moreover, suggest that assessment of operators' ability to recover from unforeseen events should be prioritized when evaluating the adequacy of human-automation interaction. When unforeseen events occur, the mitigation and recovery process cannot be guided by operating procedures alone, and the operators heavily depend on the information provided in the human-system interface. [Chapter 15](#) focuses on task complexity, which has been a topic in a range of studies. Key questions are: How can complex tasks be described? How does the crew cope with complex scenarios? The studies suggest that the interaction between task complexity and the crews' work processes is key for understanding how scenarios can become complex for the crew. Ambiguous, missing or misleading information are critical determinants of task complexity as they result in problems recognizing and integrating the indications of faults. [Chapter 16](#) describes the first phase of the international human reliability analysis (HRA)

empirical study. This study uses HAMMLAB data in a different way than the studies described in other chapters in this book. Here, we are not studying a particular human factors topic, but we are using the HAMMLAB data as a reference to evaluate predictions from HRA methods. The goal is to develop an empirically-based understanding of the performance, strengths, and weaknesses of HRA methods. [Chapter 17](#) addresses the issue of work practices and cooperation between operators in both a near future and a far future perspective. The research on near future operational environments is concerned mainly with the transition from panel-based to hybrid and computer-based control rooms. The research on far future operational environments focuses on new operational concepts that include use of Virtual Reality technology, and on design of advanced reactors. [Chapter 18](#) describes the augmented and virtual reality (AR/VR) research activities in Halden since 1998. Novel applications of VR and wearable AR systems have been explored in order to provide guidance on why and how to use these technologies. Early work focused on evaluating the use of virtual prototypes for control room design, while later work included radiation visualization and training studies as well as comparative technology studies.

The last part of the book, *outlook*, contains three chapters. This part describes how knowledge obtained in HAMMLAB has been transferred to the industry, and discusses future directions for HAMMLAB studies in terms of research topics, methodologies, and technical requirements. A large part of the activities in HAMMLAB and the work within the Man-Technology-Organisation (MTO) sector at IFE has been performed within the OECD Halden Reactor Project. However, many projects are performed directly for the industry, and [Chapter 19](#) gives an overview of the knowledge transfer to industry from HAMMLAB related research that has been taking place over the years. [Chapter 20](#) addresses how human reliability analysis (HRA) can be informed by human performance research as performed in HAMMLAB. It first discusses research needs for HRA, including the need for data to validate and improve HRA models and techniques, and the qualitative and quantitative results they produce. Next an experimental paradigm for research is presented, and the role of HRP in addressing HRA needs is discussed. [Chapter 21](#) concludes the book. This chapter also addresses HAMMLAB studies, but this time from the perspective of future research. It first outlines how the nuclear industry and nuclear power plants may change in the coming years. These changes include: new generations of reactors will be introduced, with new reactor designs and control-room technologies, and existing plants will be upgraded and modernized. Based on this scenario, the chapter discusses a set of potential research topics for HAMMLAB in the future. Moreover, future research methods and technical requirements for future studies in HAMMLAB are discussed.

The book allows the reader to follow the progress made across the first 25 years of HAMMLAB's history. It provides a window into the trends, challenges, technological evolutions and industry needs that have driven HAMMLAB's research agenda in this period, as well as into the methodological and theoretical developments in this applied human factors research. The photos used to illustrate the

chapters describing early HAMMLAB studies do not all meet the present day standards. They are, however, still included, as they are part of the history. When reading the individual chapters, you will find many references to Halden Work Reports (HWRs). HWRs are available only to members of the HRP for five years after the initial publication. After five years, the vast majority of these reports become publicly available, and can be obtained via the OECD Halden Reactor Project.

The core audience for this book are researchers, practitioners, regulators and students interested in humans' role in the safe operation of nuclear power plants. Beyond this core group, the book is relevant for readers with a general interest in human factors and safety in the process industry. Topics of interest for this wider audience include human–system interface design, teamwork, automation systems, and human reliability. All chapters are written by authors who are, or have been, employed by the HRP or its member organizations. Many of the authors have extensive experience in the nuclear industry and in human factors research, and are recognised leaders in their respective fields.

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We hope you will enjoy this book, and the opportunity it offers for travelling through time across the past 25 years of HAMMLAB's human factors research.

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Simulator-based Human Factors Studies Across 25
Years

The History of the Halden Man-Machine Laboratory

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