# NUCLEAR SAFETY

## A Human Factors Perspective

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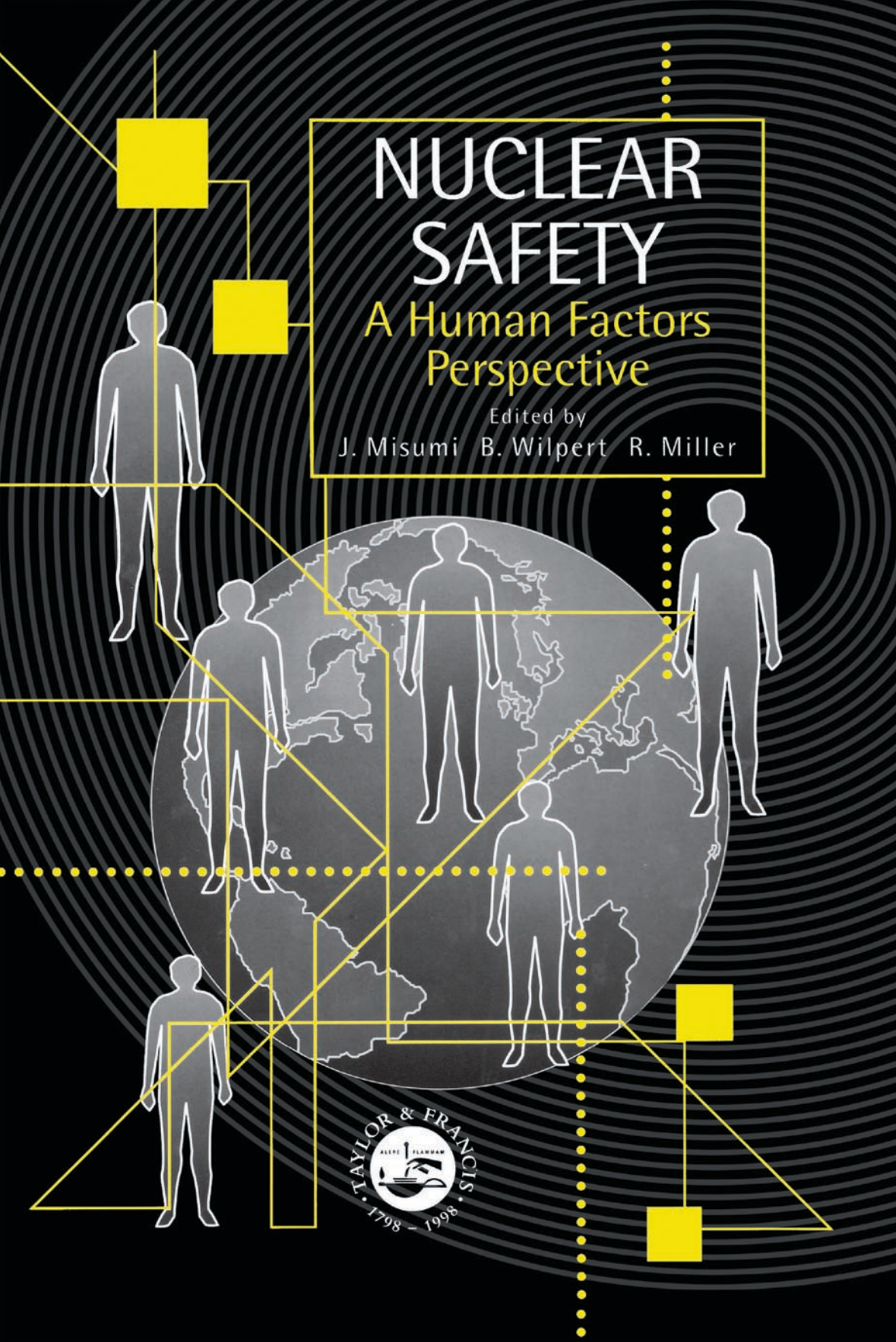

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# Nuclear Safety: A Human Factors Perspective

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# Nuclear Safety: A Human Factors Perspective

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# Preface

This volume is the result of long-standing cooperation between the Institute of Social Research within the Institute of Nuclear Safety System Inc. (ISR/INSS, Mihama, Japan) and the Forschungsstelle Systemsicherheit (FSS – Research Center System Safety) of the Berlin University of Technology. ISR/INSS and FSS decided in 1993 to organise a series of international conferences on human factor research in nuclear power operations (ICNPO) under joint financing, tutelage, and organisation. The stated objective of this conference series is 'to initiate and facilitate contacts and interaction among the dispersed ongoing social science and human factor research in Nuclear Operations of various countries in order to improve further safety and reliability of nuclear power operations' (mimeographed Conference Report of ICNPO I, Berlin, 31 October–2 November, 1994). ICNPO I brought together 40 participants, representing as many as a dozen disciplines. That first review of ongoing research on human factors in nuclear power operations resulted in a lively, interactive and worldwide network of information exchange and cooperation among researchers engaged in the field of nuclear operations. The contacts established in ICNPO I laid the foundations for a more focused conference, ICNPO II (Berlin 28–30 November, 1996), the substance of which we document in this publication for a wider audience.

Three people stand out among the many without whose efforts we could not have achieved our aspirations to unite the ICNPO II contributions in a comprehensive volume: Ulrike Wiedensohler, who managed all the administrative details, including the retyping of many manuscript revisions; Hans Maimer, who redesigned most of the graphic presentations; and David Antal, whose scrutiny and precision drastically improved and unified the style of presentation and our use of the English language. We gratefully acknowledge their critical contributions. Last, but not least, we express our sincere thanks to the ISR/INSS, whose financial support made the editorial work on this volume possible.

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# Introduction

BERNHARD WILPERT AND RAINER MILLER

## HUMAN FACTORS RESEARCH IN NUCLEAR POWER OPERATIONS: TOWARDS AN INTERDISCIPLINARY FRAMEWORK

In recent years both engineering and the human sciences have reflected a growing interest in the often intricate interaction of technical, social, psychological, managerial, and political influences on the safety of industrial systems. Systems safety, as distinct from occupational safety, is becoming the catchword. The scope of thinking in the area of occupational safety has continuously expanded from a concern with purely personal characteristics to the impact of the workplace and of organisational and managerial factors. Nevertheless, the focus of occupational and work safety still remains intra-organisational. Systems safety, by contrast, may be defined in line with Roland and Moriarty (1990, 7) as the 'quality of a system that allows the system to function without major breakdowns under predetermined conditions with an acceptable minimum of accidental loss and unintended harm to the organisation and its environment' (Fahlbruch and Wilpert, in press).

This broadening of interest has been stimulated by the variety and speed of social change:

- Technology is accelerating in many areas of social activity such as land traffic and transport, shipping, oil-drilling, and manufacturing, and in such process industries as nuclear energy production and the chemical industry.
- The ever-growing number of large-scale technical systems carries the threat of serious accidents and the potential for considerable loss and damage to human life and the environment.
- Growing international competition brings the risk of 'short-termism' rather than of long-term investment in the safety and reliability of technical installations.

These developments represent a challenge to management structures and strategies that often surpasses their capacity to change and adapt (Baram, 1998). Industrial systems safety is emerging, therefore, as an interdisciplinary problem, requiring researchers and practitioners to cooperate closely and to go beyond settled national boundaries and established scientific traditions. Hence the need for comprehensive analytic frameworks. To integrate the contributions presented in this volume, we propose to combine the open sociotechnical systems approach (Emery and Trist, 1960) with a broad understanding of human factors.

The open sociotechnical systems approach provides a context within which to examine work systems as a social and a technical subsystem. The social subsystem comprises components such as organisational culture and managerial practices, inter-organisational relations, and the division of labour and roles. Only the best quality and combination of technical equipment and the components of the social system will optimise system outputs such as productivity, reliability, and safety.

Analysing the functioning of systems from the perspective of open sociotechnical systems allows the complex interaction of relevant factors to be considered on different systems levels (Reason, 1990). However, since any given system may be seen as a component of a larger system, the question is: where do the boundaries of a given system lie? The answer to this question depends on the ultimate goal of the analysis. In our case it is to ensure systems safety. In other words, the system and its boundaries must be conceptualised as the totality of all factors, elements, and components that contribute to, and otherwise influence, safety.

For our purposes, the social system is divided into four parts (Wilpert *et al.*, 1994):

- The individual subsystem (the acting person (operator) and those functions relating to his or her workplace).
- The *work* group or team (several persons with a common work task and group-specific characteristics – e.g. competencies, norms, and social relations).
- The organisation (comprising managerial and organisational structures, rules, and regulations).
- The extra-organisational environment (all groups or organisations lying outside the focal organisation but contributing to the goal of safety).

This conceptualisation enables us to offer an overall 'landscape' within which to locate the respective foci of the chapters in this volume (see Figure 1). The main topic that they address may be either within one of the five subsystems or at the interface of two or more subsystems.

What should be regarded as the 'human factors'? The issue is important because the everyday understanding of the expression differs from its scientific use. For many practitioners human factors denote human error. In narrow ergonomic conceptualisations only immediate human–machine interface elements are considered as part of human factors. Our view of human factors is, however, broader than that

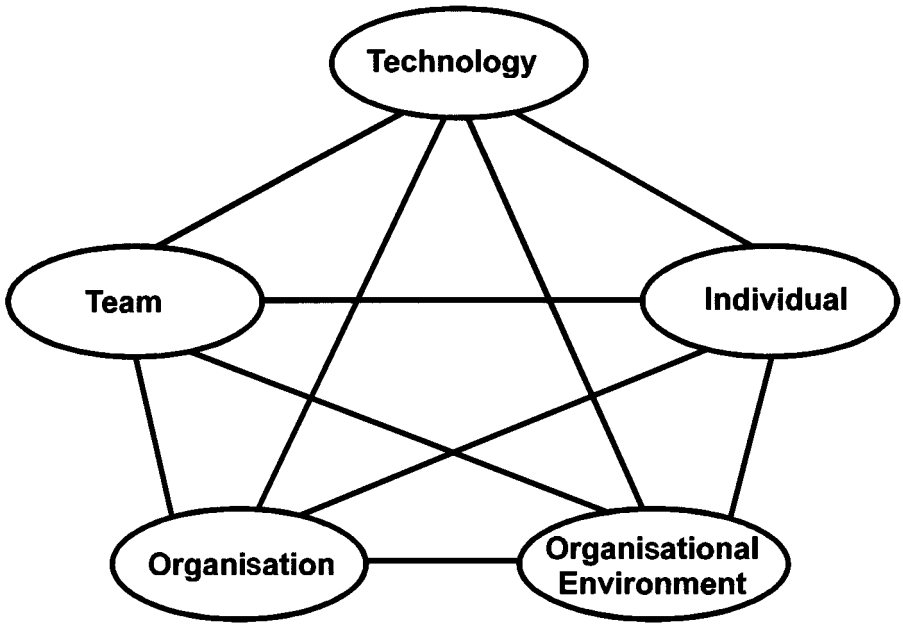


**Figure 1** The five subsystems of a nuclear power plant as a sociotechnical system.

in common parlance or in narrow scientific definitions. It was best defined by the Electric Power Research Institute (EPRI) of the US nuclear power industry. Human factors are 'all the variables in a work situation that interactively shape personnel performance' (EPRI, 1988, p. 2). Such factors may include extra-organisational influences such as overregulation and tight control from regulatory bodies. These variables can ultimately reduce the creativity and responsibility of individual operators in their work setting.

The book is divided into four main sections corresponding to the four social subsystems described above. Each section begins with introductory notes that relate each chapter to the five subsystems shown in Figure 1. Contributions to Part One focus on the environmental aspects of nuclear operations: general cultural issues and inter-organisational relationships. Covering the whole gamut of this subject, the authors present findings of comparisons between nuclear power plants in different countries, demonstrate cultural impacts on safety behaviour and technical design, examine characteristics and approaches to measurement of safety culture, and discuss environmentally induced problems and interventions for change. Organisational features and their impact on nuclear safety are the primary focus of Part Two, where the authors explore such topics as organisational structure and leadership, and consider various points of views on optimisation measures. Part Three relates to group and individual performance. Part Four offers a cross-sectional perspective: learning from experience through different strategies for studying incidents and accidents.

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PART ONE

# Nuclear power operations and their environment: culture and inter-organisational relations

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# Introduction

The contributions in Part One present different viewpoints about the way nuclear safety is embedded in an organisational or cultural context. In terms of the socio-technical systems approach, these chapters deal with the subsystems called 'organisation' and 'organisational environment' and with their manifold interactions.

Touching on basic epistemological issues, Rochlin takes the position that nuclear safety cannot be understood in terms of objective rules and procedures, but must instead be regarded as a socially constructed element of culture.

The influence of national culture on safety is investigated in different ways. Wahlström identifies differences in the safety practice of two countries, whereas Moray shows how the design of control rooms, including ergonomic recommendations, are influenced by culture. Bourrier, in her comprehensively researched contribution identifies different strategies of resource allocation in French and American nuclear power plants.

The increasing importance of safety culture, which may be placed at the interface of organisation and environment, is taken into consideration in the contributions by Meshkati, Semmer and Regenass, and Ignatov. Meshkati shows how dimensions of national culture interact with components of safety culture. The contributions by Semmer and Regenass and by Ignatov address the problem of measuring social norms as an important element of safety culture.

A holistic viewpoint of safety is taken in the contribution by Becker and that by Wilpert, Fahlbruch, Miller, Baggen, and Gans. Both chapters are an examination of the interaction between organisational factors and the organisational environment. In discussing obstacles to open communication about safety aspects, Becker points out intra-organisational barriers (e.g. hierarchical constraints) as well as environmental factors (e.g. the political situation in Germany). Wilpert *et al.* describe the 'interorganisational field' of safety in Germany, meaning all organisations and institutions – their interactions – contributing to the safety of German nuclear power plants.

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CHAPTER ONE

# The social construction of safety

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Empirical work on organisations that have been managing hazardous technical operations with some degree of success reveals what might be best characterised as an internal, socially constructed, proactive culture of operational safety, rooted not in the assumption that operations are inherently safe or that operators are secure in their knowledge, but in the belief that operations are inherently dangerous and the knowledge base imperfect. Rather than grounding their culture in tales of heroic successes, operators and managers of these systems use recent examples of real errors or near-misses resulting from overconfidence in system design or operator ability as a foundation for socially constructed images of risk for promoting safety in the operational milieu. Their deep concern about the consequences of constructing an internal image that is too secure, either instrumentally or socially, is consistent with recent sociological and psychological explorations of similar organisations.

The difficulty for analysts and system designers is understanding how to identify such cultures and the means by which they are created and maintained. Because these cultures are socially constructed, they arise as much from interpersonal and intergroup interaction as from the more commonly studied interactions with external designers and regulators. Because the interaction is anchored in cultural dynamics, there are wide variations in its manifestation even for similar plants in roughly similar settings. The analytical problem is to identify the means to correlate the social construct of operational safety with empirical observations concerning the nature and role of human operators in maintaining reliability and controlling risk.

*There are old pilots, and there are bold pilots, but there are no old, bold pilots.*
Anon.

When the Berkeley 'high-reliability organisation' (HRO) group first set out to examine the role of operators in maintaining safety in a variety of complex, high-technology operations, the intention was to produce a reasonably ordinary,

organisational study, essentially positivist in orientation and based on a combination of behavioural analysis, survey research instruments, and empirical observation (La Porte, 1996; Rochlin, 1993). My HRO colleagues and I sought to link what operators believe, or say they believe, about their performance and the performance of their systems with observations about operational 'reliability' that involve measurable indicators. In some cases, such as aircraft launches from an aircraft carrier, indicators of this sort could be derived if the data were made available. In others, such as nuclear power plant operations or air traffic control, it soon became clear that there was no baseline for measuring failures. Moreover, and more surprisingly, it became clear that, even if such data were available, they would not provide indicators of operational safety. Paradoxically, operators' perceptions of potential risk were an essential element in their construction of an environment of safe operations (Roberts, 1993; Rochlin, 1996).

*Operational safety* is more than a culture. Even within the organisation itself safety is a social construct. It is therefore difficult not only to measure but to analyse and characterise with the usual analytic tools of organisational theory. It involves *élan* and modesty, pride in past accomplishments and concern about future ones, cooperation between operators and technical cadres and also tensions between them, as well as an acknowledgment of the importance of close oversight by managers and regulators, and a demand for independence of action. The sense of accomplishment is defined as a blend of autonomy, safety, and production goals (Roberts, Rousseau, and La Porte, 1993). But what sort of blend? And to what extent can a constructed belief in operational safety be measured against some set of observations or empirical measures, say, of reliability or of the control of risk?

Most of the literature on risk and reliability in potentially high-consequence, sociotechnical operations lacks not only an adequate, 'operationalisable' definition of operational safety, but even a means for defining and expressing it. As La Porte (1996) has pointed out, attempts to define what has become known in the literature as a *safety culture* have been overlaid with the twin anxieties about the complexity of emergent systems and the limits on the performance and capabilities of individual human beings. The culture of reliable operation that the Berkeley HRO group has reported on is not what most people mean by a culture of safety (International Nuclear Safety Advisory Group [INSAG], 1991): it does not correspond to searches for excellence (Deal and Kennedy, 1982; Peters and Waterman, 1982), and it is not brought about at the institutional level by the assumption of collective regulatory responsibility (Rees, 1994). Weick (1987) has perhaps come closest in characterising it as bringing empirical research on operational norms and procedures to bear on more familiar organisational studies of safety culture (Weick and Roberts, 1993).

Scarry (1985) pointed out that most human languages have only a very limited and indirect vocabulary for expressing the character or nature of pain. Safety seems to have that same elusive quality, both as a term and as a construct. It is much talked about in general, but little examined in detail. Even professional analysts of risk and reliability tend to resemble the popular press in paying quite a lot of attention to examining what goes wrong and why, very little attention to situations

where something could have gone wrong but didn't (near-misses), and even less attention to those cases where, in principle, quite a lot could go wrong, but very little has. In the remainder of this chapter, I first mirror the argument to discuss not risk, but safety, as a social construct, and then use the empirical work of the Berkeley HRO group to carry that discussion over into the more circumscribed universe of the operation of nuclear power plants and other sociotechnical systems that have, as an inherent property, the potential to cause considerable and dramatic public harm and, as an observable property, their failure to have done so.

## 1.1 THE SOCIAL CONSTRUCTION OF RISK

A fundamental premise of much of the literature on risks, crises, and accidents, including a great deal of the organisational literature, takes a default definition of safety as the antithesis of error, or as a residual set defined in terms of the negation or absence of risk (Bonaca, 1991; INSAG, 1991; Pidgeon, 1991; Ralph, 1988). This definition is an instrumentalist orientation that rests upon a set of philosophical, epistemological, ontological, and normative assumptions that can be summarised in terms of a formalist, functionalist perspective of control that emphasises positive action and predictive models ('t Hart, 1993). The professional literature on risk in complex, technical systems has long been dominated by formal, engineering-oriented definitions and approaches that largely eliminate the social dimension, or at the very least externalise it, severely constraining the range and scope of social and institutional analysis that can be applied (Clarke and Short, 1993). That perspective may be sufficient for automatic systems, but is woefully inadequate for sociotechnical ones.

This paradigm is most deeply embedded in the classic engineering definition of risk as the product of hazard (potential consequence) and probability of occurrence. After the risk has been calculated according to some method (such as fault-tree analysis combined with probabilistic failure rates), certain numbers are generated (for example, $x$ events of a certain type per million operations, or per year of operation). Where human operators and operations are concerned, the result may be further augmented by a variety of empirical or psychological means for estimating the probability of single-mode or collective human error. This procedure yields a more sophisticated approach to estimating how often a system will experience an error or failure with a certain range of consequences, but what then? It may be risk in a formal sense, but it does not map well on to the world of human action. It does not deal with the issue of whether such a risk is accepted, or acceptable, to the operators, the operating company, the corporation, regulators and other watchers, or the general public.

It was always clear that neither individual nor public response to risk was in accordance with the rank ordering and analytic findings of objective risk analysis. In its most classic expression, many people who are afraid to fly are hardly concerned at all with the risk of driving to the airport. The positivist response to this paradox has been to cast the subjective dimension in terms of a formal scientific-economic

model, in which contingent valuation is used in the form of revealed preferences. The fundamental premise, more widely elaborated since, is that there are different categories of risk perception and risk acceptance that depend on the interaction between the individual and the source of potential harm (Hiskes, 1996).

The classic analysis by Starr (1969) incorporated the social and behavioural dimension by dividing risk exposure into voluntary and involuntary. This approach was intended to preserve the positivist paradigm of rational calculation and planning. However, the work of psychologists such as Slovic and Fischhoff showed that no purely economic-rational model, including that of revealed preferences, could adequately encompass the non-rational ordering and cycling preferences displayed in actual practice (Slovic, Fischhoff, and Lichtenstein, 1976). Instead, it was necessary to extend the notion of preferences to include not only the nature of the risk (i.e. what the consequence is), or its familiarity, but also such behavioural characteristics as whether the individual believes that he or she is in control of the risk-producing activity, or can only react to it.

In recent years, social and political aspects of the divisions in the interpretation and meaning of risk have been emphasised in views based rather explicitly on both individual and collective dimensions of risk perception (Clarke, 1989). This perspective was most notably framed in cultural terms in the work of social theorists such as Beck (1992) and Luhmann (1993), who sought to define risk in social rather than technical terms. Taking a slightly different path, theorists such as Thompson, Douglas, Ellis, and Wildavsky have developed a methodology for policy analysis that is conceptually similar to the economic-psychological division of voluntary and involuntary risks. They seek to comprehend variations of risk acceptance in terms of cultural variations in political and social groupings, each of which constructs socially a different interpretation and meaning for the nature and importance of different categories and types of risk (Douglas and Wildavsky, 1983; Thompson, Ellis, and Wildavsky, 1990).

Hiskes (1996) and others working on the social construction of risk from a more postmodern perspective have gone further, arguing that risk is neither entirely instrumental nor wholly external, but that it is an emergent property of social (or, in this case, sociotechnical) systems. A product of people's common lives, it emerges from the interactions of individuals, and is manifested in the social construction of common narratives of the perils and progress of collective interaction. From this perspective, risk is a group phenomenon with a dual character, as a set of more or less objectively determined properties of the external world and as a collection of subjective responses to that world. In such constructivist views the perception and acceptance of risk is an intersubjective social act, a 'speech act' if you will (Searle, 1969).

The cultural-theory school has, however, been strongly criticised not only for being fundamentally normative but also for dealing with risk as if it consisted almost entirely of subjectivity and perceptions (Shrader-Frechette, 1991). In contrast, Turner (1978) and others have sought to find a balance by adopting a quasi-instrumental perspective, defining collective errors as a negentropic property of social systems based on the human ability to self-organise damaging events and

circumstances that are not decomposable at the individual level. Over time, other schools of thought on risk have emerged and have sought better coupling between the social sciences and the technical realm, yet these have remained framed within essentially social rather than technical definitions, such as 'the definition of risk is essentially a political act' (Kasperson, 1992, p. 155) or a sociopolitical act (Turner, 1989). Even those who have chosen to argue that risk hardly exists at all as an unchangeable feature of an objective physical world, but is a construct that the human imagination overlays on the surrounding world, acknowledge the world as a tangible, and not just a social, reality (Jasanoff, 1993).

I do not intend to delve extensively here into the interesting and provocative debate about the two bodies of risk theory, the objective and the subjective, or into the question of whether they are ontologically complementary or epistemologically incompatible. Rather, my purpose is to point out that, whatever the merits and strengths of objective risk analysis, it does not provide either a definition or a description of the social interpretation of being at risk. Positivist calculation of risk may be considered to have a certain degree of objective reality, particularly when it expresses purely technical probabilities, but it is given meaning by the filtering of empirical data and formal models through subjective interpretations and intersubjective constructions of representation and meaning. Constructivist-positivist interpretations such as that by Turner (1989) have gone much further in exploring the notions of collective interaction and social construction, but attempts to encompass intersubjectivity, representation, and interpretation more fully have been difficult at best. Although abstract and constructivist, workable models of risk from technical systems that present physical dangers must still acknowledge that representations of risk are not entirely separable from the objective reality represented; it is interpretation and meaning, narrative and discourse, if you will, that shape responses, beliefs, and actions.

## 1.2 THE SOCIAL CONSTRUCTION OF SAFETY

Three recent sets of news stories may be used to frame the growing importance of studying safety as a positive attribute of sociotechnical systems. One, having to do with an unprecedented rash of crashes by high-performance F-14 naval fighter aircraft, questioned whether the pilots were becoming overconfident both in their abilities and in the airframes, thereby rejecting the familiar homily quoted as the epigraph of this chapter (Schmitt, 1996). The second set centred on Vaughan's (1996) admirable analysis of the *Challenger* accident, in which she examines the consequences of constantly reconstructing perceptions of operational safety to incorporate and normalise survived errors (Broad, 1996). The third set, with opposite implications, arose from the discovery that the US Federal Aviation Administration (FAA), anticipating the introduction of a new and more advanced air traffic control automation suite, had already cut back on the number of maintainers familiar with the present, quite antiquated equipment, and that controllers were not only nervous

about the consequences, but manifestly concerned that operational safety was being compromised (Wald, 1996).

The perspective adopted in all three cases was not the usual, normal-accident argument – because complex systems are inherently incapable of being operated safely, accidents are only to be expected (Perrow, 1984; Sagan, 1993). In contrast to these traditional approaches, which take safe operation to be a period between accidents, all three sets of news stories accepted the premise that accidents are untoward events in these systems, and that operational success, defined as avoiding both public harm and operational failure, was, or should have been, the normal and appropriate circumstance, even in a set of very demanding operational conditions with very high potential consequences. That risk is increasingly discussed as a social construct is no longer surprising; what is remarkable is the growing perception that safety is socially constructed as well.

It is entirely possible to define safety as the negation of risk, just as it is possible to define health as the condition of not being noticeably ill, or life as the state of not being noticeably dead. Although such framing is not uncommon when one has recently been exposed personally or vicariously to a direct risk or the threat of illness or death, a statement that one is 'alive and well' is rarely deconstructed in such objective, positivist, medical terms in the wider and more general social and cultural context. Playing against such narrow meanings, expressions of good health or good life are most often social constructions that involve meanings and interpretations that are more complex, more general, and more difficult to quantify.

Referents to safety in common usage are similarly dichotomised. *Webster's Seventh New Collegiate Dictionary*, for example, first defines the word *safe* passively and positivistically: 'free from harm or risk,' the opposite of hazardous or dangerous. But the gates of ambiguity are then opened by *Webster's* second definition: 'Secure from threat of danger, harm, or loss,' which is not quite the opposite of danger, harm, or loss, respectively. Although it is possible to interpret the latter statement narrowly and objectively, it would be broader to consider both *threat* and *security* as perceptions, in which case safety is largely subjective, or even to go further and consider *threat* to be an expression of intentionality, and *secure* to be a perceptual frame, in which case both are inherently and irrevocably intersubjective.

Divergences between individuals with regard to their perceptions of being safe may be as wide as the divergences between individual and collective perceptions of safety and the results of objective analysis. *Being* safe and *feeling* safe can be quite different things. In parallel with the literature on risk, the question of whether an individual is in a situation over which he or she has control, or one in which that person does not, may strongly affect perceptions. But there remains a fundamental difference. Risk is subject to logical parsing, because it is an affirmation, an expression that something that could happen might happen. Safety, defined as the state of being 'not at risk,' is not. It is a conditional negation, an expression that something that will cause harm or loss might not happen, or that something that will happen might turn out not to be harmful. Moreover, one must distinguish between the active construction of safety and the feeling that one is safe: the latter may be based more on suppression or repression of the knowledge of risk than on its calculation.

The analogy with health can be and has been extended further. Reason (1995), for example, pointed out that health can be thought of as 'an emergent property inferred from a selection of physiological signs and lifestyle indicators' (Reason, 1995, p. 1716). He then constructed an analogy with complex, hazardous systems, commenting that assessing an organisation's safety health is like assessing the physical health of a patient, in that it requires sampling from a potentially large number of indicators. However, to argue further that these systems can be parsed to generate separable dimensions along which organisational safety might be assessed is to frame the notion of emergence in an overly positivistic way.

To take a real world example, I feel safe at the moment in my study in my home in Berkeley, California. This feeling encompasses many things. I am probably accurate in not being concerned about hurricanes, floods, tigers, or stampedes. I do not imagine (except by an effort of perverse will) that I might be at risk from falling aeroplanes, meteorites, terrorist bombs, assassination, or the explosion of a gas main. But my perceived risk of the potential and very real possibility of an earthquake is kept low partially by denial, partially by a number of measures taken to reinforce the house and provide for medical and other contingencies, and partially by a belief that there is a collective response system that will help. I am not calculating the risk of heart attack or cancer, over which I have very little control, or of repetitive strain injury, over which I imagine I have a lot, although I might calculate those risks if I were all alone or in a remote area where medical and emergency help would be difficult to find. When I went out this morning, I crossed the street, drove to the store, came in proximity to or touched people who might well have incurable communicative diseases, purchased several food products that could (conceivably) prove harmful when ingested, and bought a package of cigars (no comment).

In short, my own construction of safety (and risk) shows an absolutely typical mix of evaluations of individual and collective behaviour, personal and social judgment, subjectivity and intersubjectivity, and representation and interpretation. It involves not only voluntary actions to control risks in the environment, and often implicit assessments of the low risk presented by other potential sources of harm over which I have no control, but also the acceptance and definition of my individual, personal safety as a series of interactive social contracts and constructions – for example, the quite different perceptions and reactions evoked when I am out on the streets of a completely strange city at night.

This effort at analysis is more socially grounded than most, yet it still omits almost completely another important set of considerations arising from the active nature of the social and political dimensions of individual or organisational environments. Safety, like risk, can be created and manipulated by others, whose purposes, objectives, and interpretations in its shape and direction are either unknown or masked. This interpretation goes beyond the social constructivist perspective that social reality cannot be objectively assessed, introducing in addition the extent to which safety is, or may be, contingent upon different subjective constructions given to it by different actors ('t Hart, 1993).

As with the business of trying to generate the perceptual and cognitive dimensions of the social construction and definition of risk, there may be a wide gap

between the subjective evaluation of what is safe and any set of comparative empirical indicators that might be constructed from data sets or observations. But that discrepancy is even more difficult to determine for safety, because the objective dimensions of risk are more easily defined than the subjective, particularly in those cases where the source of the risk is entirely external and largely probabilistic. Moreover, the two notions of subjective and objective risk are not entirely unconnected. Where safety is an interactive social property, a collective social property, or both, where it depends upon subjective indicators such as beliefs and behaviour, as well as upon intersubjective ones such as signalling or behavioural assumptions, there are many situations where safety is a collective and self-reinforcing property of the system. However, it must also be admitted that there are cases where actions predicated on the perception of safety may also, objectively, decrease it. As with risk, the most important, and least commonly addressed, analytic problem is to separate, identify, and characterise these situations in a way that provides guidance for identifying which of the cases is which, and why.

## 1.3 OPERATIONAL SAFETY AS A SOCIAL CONSTRUCT

The epigraph of this chapter has been familiar to pilots for so long that its origins are lost. What is important, however, is not how it originated but how commonly and widely it is known, and how often it is invoked as a token within the community. It has also been expressed in another significant way by both civil and military pilots, all of whom will repeat, in one way or another, the maxim that pilots are most at risk when they have gained enough experience to be overconfident – that is, to begin believing that flying is a safe environment rather than an inherently dangerous one. What increases safety over time is not just experience, but the recognition that they work in an environment that is always subject to unexpected events or unfamiliar conditions.

To recreate the paradox raised at the beginning of this chapter in particular circumstances, pilots' continuing belief that flying is inherently risky and that the environment in which they operate is potentially hostile is acknowledged by them to be a major part of their culture of safe operation. Purely exogenous or uncontrollable dramatic technical failure aside (e.g. bombs, fuel-tank explosions), what has created the present low level of serious operational errors and accidents is a dialectic of safety: the result is to foster high confidence in the inherent quality and design of the equipment and the training and expertise of oneself and other members of the crew, while at the same time remaining alert and attentive for signs or signals that a circumstance exists, or is developing, in which confidence is erroneous or misplaced. One of the most remarkable findings of the HRO team's extensive semistructured interviews with pilots, air-traffic controllers, and nuclear plant operators and maintenance people is the ease and unselfconsciousness with which they appear to maintain this duality of representation (Bourrier, 1996; Rochlin and von Meier, 1994). They clearly see no contradictions in the dichotomous

responses my colleagues and I can elicit by varying the framing and wording of specific questions put to them.

This finding is perhaps clearest in an analysis of US operators' responses to the incredible web of detailed and formal rules and regulations with which they must comply (La Porte and Thomas, 1995). Almost every operator who was interviewed felt that regulation at the required level was intrusive, at times distracting, and often far more detailed than required for the task. Nonetheless, almost every operator also argued that the rules and regulations they lived with were, by and large, necessary and important. There was little evidence that this seeming contradiction created in them a sense of cognitive dissonance or permanent tension between seemingly incompatible beliefs. Instead, the lack of resolution of the dialectic is almost always explained away with an often implicit hypothesis that a harmonious synthesis is achievable, but that it is blocked by exogenous factors such as bureaucratic difficulties, public sensitivities, or political ignorance. What they generally could not tell us was the extent to which potential stresses were relieved by incorporation rather than resolution, by designing into the operators' regular procedures regulation-compliant behaviour that was specified to be functional whether it was or not. And incorporation is a very accurate description of the process: there were many aspects of operator task design and performance for which operators could no longer tell whether the design and specification had originally arisen from internal evaluation and review, or had been imposed to satisfy the expectations or demands of outside watchers and regulators.

In an article on 'hero stories,' another member of the HRO research team, Paul Schulman, provides the groundwork for beginning to understand such behaviour and parse it according to industry, activity, and function (Schulman, 1996). What he noted first was a sharp contrast between organisations in which hero stories were prevalent and welcome (hero-embracing) and those in which such stories were rare and not encouraged (hero-avoiding). Hero-embracing strategies emphasise extraordinary performance and rapid response, the need for individual actions to accomplish goals and maintain performance. This need is most evident in organisations such as the Marine Corps, fire departments, electric utility linemen, and, in fact, naval pilots. These stories serve, among other things, as an effective means for organisational learning and the maintenance of cumulative knowledge.

In contrast, not only were hero stories almost completely absent among nuclear power plant operators, their presence would have been disturbing. In this context 'hero' is a term of derision or criticism, describing an operator who will act on his or her own personal achievements and judgment, with little regard for the collectivity or for rules and regulations (in the United States, the contempt is often summed up in the derogatory term 'cowboy,' in itself worthy of an entire deconstructivist essay). Safety is sought through collective action and interaction, through shared knowledge and responsibility. Organisational learning is formalised, and cumulative knowledge is transmitted not through legends or narratives but through the creation and modification of formal procedures. The hero-embracing organisation sees its task environment as decomposable into a series of unstable and unpredictable events, and defines safety in terms of the capacity to cope with a constant