Chapter 1
Risk in Historical Perspective: Concepts, Contexts, and Conjunctions

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Although the etymological roots of the term risk can be traced back as far as the late Middle Ages, the modern concept of risk appeared only gradually, with the transition from traditional to modern society. The modern understanding of risk presupposes subjects or institutions, accountable for their actions, that make decisions under conditions of apparent uncertainty. Some apparent uncertainties, however, can be measured or quantified probabilistically and are, therefore, more precisely called "risks". Situations of "risk" in human society can thus be "managed". Relying on probability calculation, which emerged during the 17th and the 18th centuries but became truly prevalent only in the 20th century, risk became a theoretical focus designed to bolster a scientific, mathematically-based approach toward uncertainty. Insurance companies led in demanding and developing a concretely applicable concept of risk, since calculating the probability of premature death or material hazards related to either humans or material things, such as ships, buildings, and their contents, was essential for their core business and success. However, by the middle of the 20th century—an Age of Extremes, as it has been aptly characterized—nuclear weapons and their use in Japan and subsequent further development early in the Cold War dramatically increased awareness of potential hazards derived from these and other achievements in science, engineering and warfare. Therefore, the Age of Extremes stimulated more and new research on risk. With new tools, such as operations research, digital computers, systems analysis, and systems management, all of which had been introduced in the military and aerospace sectors in the course of World War II, the intellectual resources necessary to estimate the extent and the probability of failures and accidents in nuclear warfare and beyond increased dramatically. Out of the Cold War effort to create the "Peaceful Atom", nuclear-power reactor safety studies became landmarks in risk analysis, and this type of study later achieved relevance in many more areas. This chapter seeks to explore the evolution of risk research and risk management in its social and political contexts in order to understand the underlying concepts of risk and safety as social constructs. The

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historical survey focuses mainly on the last two centuries. It starts with the advent of the modern era when with spreading bourgeois virtues it became common to plan for the future but not to bet on it. This involved an increasing need to calculate future uncertainties in order to manage them as risks. The study stops at the end of the Cold War, when the collapse of the socialist bloc settled the risky confrontation between the two opposing societal camps. By no means did the termination of the Cold War end the story about risk. On the contrary, as late modern societies accumulate more and more knowledge they simultaneously increase the amount of ignorance that is the cause of newly emerging risk. How these risks are tackled is the topic of the other chapters in this book. This historical survey does not aim at completeness but rather at understanding the major transformations in the evolution of risk. Thus, not all areas in the history of risk are covered here; for instance, the important field of financial risk is treated by other Chap. 4.

Keywords Food safety regulation · Probabilistic health risk research · Quality and reliability engineering · Reactor safety studies · Steam boiler safety

The Facts

- While mathematicians in the era of the scientific revolution and the enlightenment began to approach uncertainty as probability, the early-modern passion for gambling shaped notions on risk as genuine uncertainty and, therefore, precluded the early application of the nascent tools of probability.
- Both the quality of uncertainties and attitudes toward them changed in conjunction with the great political, technological and social transformation of societies in the Western world since the beginning of the 19th century.
- Human-made dangers and threatening uncertainties resulted from the introduction of new technologies, from urbanization and from the industrialization of food; these induced Western societies to commence framing and managing uncertainties as risks.
- The burgeoning insurance industry, which, since the 19th century, sold its customers a new degree of control over uncertainty, evolved as an important promoter of research as to the causes and prevention of risk, and became an important contributor to the quantitative understanding of risk.
- The adoption of state compulsory accident insurance especially gave rise to the emergence of industrial medicine, which also furthered probabilistic approaches in medical research and industrial hygiene.
- The development of quantitative approaches to system safety and reliability in the Bell Telephone System in the 1920s, as well as the German beginnings of "Großzahlforschung" (see Sect. 3.5), constituted an important building block for the emergence of quality and reliability engineering and Probabilistic Risk Assessment in various fields of complex engineering systems.
- Safety engineering in the aerospace and defense sector gave rise to pioneering quantitative as well as qualitative methods of risk assessment.

- The so-called Rasmussen Reactor Safety Study, issued October 1975, was a contested and yet celebrated breakthrough of Probabilistic Risk Assessment, and its method spread to other branches as well as countries beyond the US.
- Risk research and risk management have become an increasingly professionalized endeavor since the 1970s, when late modern societies began to pay more attention to the swelling uncertainties that accompanied the experience of increasing ignorance as an unavoidable side effect of the production of more and more knowledge and unbounded Promethean technological and industrial development.

1 Introduction

Risk gained the popularity of a keyword in the latter part of the last century (cf. Williams [99]). Politicians, civil organizations of various kinds, researchers, experts, doctors, generals, publishers, and many more people and institutions felt the need to tackle problems of risk in a more systematic fashion (Renn [34, 35]). In 1980 the international risk research community established its own professional society—the Society of Risk Analysis (SRA)—which has published Risk Analysis: An International Journal since 1981 (Thompson, Deisler, and Schwing [38]). When German sociologist Ulrich Beck produced his analysis of late modern society under the thrilling title Risk Society shortly after the Chernobyl reactor catastrophe focused people's attention on the enormous dangers of nuclear power plants, the book immediately became a big success (Beck [2]). According to Luhmann, this phenomenon of sustained focus on risk reveals a remarkable characteristic of late modern society; as he argues, risk became the main approach to addressing the problems of uncertainty (Luhmann [24]).[1] Uncertainty, however, is a fundamental anthropological experience. People in all societies have had to deal with uncertainty in one way or another. Thus, if we want to understand the significance of risk in our present society, we need to explore the following questions: when did the attitude toward future uncertainties change so that the understanding of uncertainties became narrowed down to risk? How did the modern concept of risk determine people's ways to deal with uncertainties? How widely accepted has modern risk analysis become, in what ways has such analysis proved to be particularly problematic, and in what manner has risk analysis become professionalized?

2 Pre-modern Ways of Coping with Uncertainty and the Emergence of Proto-Modern Notions on Risk

Members of pre-modern societies experienced uncertainties in manifold ways as their success of everyday action was highly vulnerable to a great variety of unex-

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[1]On the classical differentiation between uncertainty and risk see Knight [22]. As a well informed and yet popular story of risk see Bernstein [43].

pected or inalterable events, such as premature death, famines, natural disasters, wars, epidemics such as pestilence and the plague, violent politics, and so on and so forth. Most of all, religious belief systems and magical as well as divinatory practices provided methods for coping with these uncertainties. Confidence in the wisdom of gods helped humans to accept uncertainties as one's fate, and collectively practised magical rituals did so as well (cf. Luhmann, 16–17 [24] and Douglas and Wildavsky [12]).

Fateful resignation, though the main method, was just one way to cope with uncertainty. Already in the 12th and 13th centuries a new attitude toward uncertainty emerged in the Italian cities and city states. Merchants and seafarers started to take uncertainties as a chance to improve their welfare. Speculating on a fortunate course of events, they ventured out beyond known places and thus risked long sea journeys. Here uncertainty was no longer seen only as danger and passively endured as fate, but taken as a challenge that could pay off if their calculations worked out. Calculations, however, meant nothing but informed guesses at that time when available information remained exceedingly less than sparse. It is important to note that in this very context the term "risk" came to be used (cf. Bonß, 49–50 [4] and Luhmann, 17–18 [24]). While risk expressed a new, active, and positively connoted stance on uncertainty, it also gave rise to a new need. In order to get the calculations right, risk takers wished to learn new methods of forecasting the future course of events beyond traditional practices of divination, the belief in the wisdom of gods, and resignation to an unknowable fate.

The emerging new attitude toward uncertainty spread throughout Europe, and this boosted the desire to gain control over an unknown future. This development signifies a remarkable shift from "traditional" to "modern" perspectives, as the risk seekers hoped to determine their own future. Thus they increasingly gained confidence that nature could be conquered and the world improved by human action (Bonß, 52 [4]).

In the mid-16th century risk-taking even advanced to become a new business as the new legal category of aleatory contracts revealed. According to Daston these contracts subsumed "all agreements involving an element of chance, any trade of here-and-present certain goods for uncertain future goods: annuities, gambling, expectation of an estate, purchase of a future harvest or the next catch of a fisherman's net..." (Daston, 238 [10]). In the late 17th and early 18th centuries, England's bustling capital London provided the most fertile breeding ground for the business of risk-taking, as is evident from the quickly expanding insurance market. Maritime insurance multiplied on the initiative of individual brokers who gathered in places like Lloyd's Coffee House. In addition, new branches emerged such as fire and life insurance, not to mention the many adventurous schemes that promised protection against any and every contingency of life. It was, however, not yet prudent foresight but a reckless spirit of gambling that fueled this early boom of insurance (Daston, 165 [11]).

As for the calculation of risk, however, contractors relied on rules of thumb and all forms of experience rather than statistical approaches. The fact that past experience took manifold forms and obscured any regularity prevented early entrepreneurs

of risk from attempting calculations based on systematic empirical data (Daston, 240 [10]). The practitioners' non-statistical stance notwithstanding, aleatory contracts paved the way toward mathematical probability because they put new problems and questions before mathematicians. The latter, however, remained caught in the mindset of the jurists who posed the problem when they sought to determine the fair price of an annuity or a life insurance premium. Thus, the mathematicians began to tackle the new field in terms of mathematical expectations, i.e. the product of a probability of an event and its outcome value or "payoff" (Daston, 240 [10]). Their approach to quantifying uncertainty as probability, however, worked against the application of mathematics in this early modern business of risk as the aleatory contracts defined risk as "genuine uncertainties". Quantification could have diluted the genuine uncertainty and thus would have worked against the playful rationality of aleatory contracts (Daston, 247–248 [10]). Therefore, deploying the mathematicians' new achievements of probability as a way to control uncertainty required a new attitude toward risk. The latter had to be redefined from something to be desired into something to be avoided. A favorable context for this redefinition evolved as soon as bourgeois values of familial responsibility, control, and predictability began to determine the norms of society (Daston, 182 [11]).

3 Industrialization, Urbanization and Competitive Markets: New Qualities of Uncertainty and the Beginnings of Risk Management

Within the great political, technological and social transformation of Western societies that was pioneered by the British Industrial Revolution and the French Bourgeois Revolution, the meaning of uncertainty changed substantially. In contrast to the gambler as well as the venturesome man of action in the Ancien Régime who had appreciated uncertainty as a chance to make a fortune and as a way to escape the fate of the natural as well as the religious order, the capitalist entrepreneur as well as the male breadwinner who was entitled to vote did not want to bet on the future but to plan for it. Thus, they strove to enlist knowledge in order either to reduce or to circumvent uncertainty. Gaining control on the unknown worked as a strong motive. That was, for example, the case for the French revolutionaries and the German bourgeois reformers who wanted to determine the state of society. It was also true for the agriculturalists, engineers, entrepreneurs, architects, members of the academic elite, and many others in Britain, France, Germany, and elsewhere as they all together aimed at extending human control over nature. And indeed, people who had been living in the Western world since the mid-19th century experienced a higher degree of predictability during the course of their lives when more children than ever before survived past infancy, when dwellings withstood fires for generations, when famines no longer constituted the rule but became exceptional events in the experiences of Western men and women, to name just a few most fundamental improvements in human existence.

More stability and predictability, however, did not free the urban middle class or capitalist entrepreneurs and farmers from fear. At the same time as people accumulated more knowledge and competencies to put an end to uncertainties, they increasingly felt ignorant about many things that were coming into their lives. Railroad accidents, steam boiler explosions, collapsing bridges, adulterated food, and several waves of cholera epidemics in rapidly expanding cities, among other perils, marked a new class of human-made dangers and threatening uncertainties.

How did men and women in mid-19th century Europe and North America cope with such new dangers? They developed a whole range of strategies and institutions to gain control of uncertainties and to decrease the probability as well as the extent of these misfortunes. This was the context out of which the modern politics of risk management gradually emerged, notwithstanding the fact that the term risk was only seldomly used and if so in a much narrower sense.[2] Thus, by exploring this emerging new field of politics we can learn a great deal about how the current concept of risk evolved and changed over time. We will see how, following the efforts of industrializing societies to develop approaches and institutions for regulating dangerous activities, uncertainties became framed and managed as risks and thus necessarily also gave rise to new notions of security.

3.1 Controlling Technical Risk: From Steam Boiler Associations to Safety Standard Authorities

The steam engine is often seen as a paradigmatic invention of the so-called British Industrial Revolution. Its widespread use in powering factories and river and rail transportation also decisively triggered the transformational process of introducing new perils into society because it was prone to explode, leading to deaths, serious injuries, and destruction of valuable property. Steam boiler explosions constituted a completely new form of threat because they exposed people for the first time to the destructive potential of modern technology. Therefore, steam boiler explosions mobilized a concerned public, led to pioneering scientific and engineering investigations of such "failures", and required governments to institutionalize construction and operation standards and regular safety inspections. Hence, the state felt obliged to diminish the risk of explosions and thus to establish a new concept of technological safety.

In France, as well as in Prussia and some other German territorial states, the state set up steam boiler legislation and introduced rules and institutions for inspection (for France cf. Fressoz [15] and for the German states cf. Wiesenack, 5–18 [40]). In Great Britain the owners of steam boilers established boiler insurance and introduced private inspections. In the United States, public outrage about increasingly

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[2]During the 19th century the term risk remained confined to the economic sphere and was used with the meaning of venture or hazard of loss (cf. Schulz and Basler, 452 [88]).

numerous and deadly explosions of steamboats led the US government to commission the Franklin Institute to investigate the causes of steam boiler explosions and to recommend means by which they could be prevented. The institute's investigation resulted in the first form of federal regulation of technology in the US, but the regulations and Federal power were so weak that boiler failures remained a common occurrence well into the 20th century, when the American Society of Mechanical Engineers promulgated its Steam Boiler Code in 1916 based on what became known as a consensus standards-making process (Burke [5], Sinclair [89, 90]). In the German states, at first the state conducted inspection, but this system was gradually replaced by privately founded steam boiler associations wherein boiler owners and manufacturers set up a self-organized inspection process. The associations claimed autonomy based on technological expertise that the states did not possess. But the real problem at stake here was this: who would more successfully ensure the workers' and citizens' safety with regard to technology, the authoritarian state or private entrepreneurs and engineers in a liberal market? In the years from 1866 and 1911, in all German states, 36 steam boiler associations came into being (Wiesenack, 19–21 [40]). The federal law of 1872 assigned the privately organized associations the task of inspections, and in subsequent years, until the outbreak of World War I, the German states extended the associations' responsibility of regularly conducted revisions onto newly emerging fields of potentially dangerous technological installations and artifacts such as steam vessels, elevators, motor vehicles, vessels for pressurized or liquidized gases, mineral water apparatus, acetylene-generating and -storing units, and electrical installations (Wiesenack, 38–74 [40]). The steam boiler associations took up these new fields of activity with hesitation because the new tasks had to be carried out on behalf of the state for nonmembers of the associations in technical areas beyond the specific expertise of steam boiler engineers (Wiesenack, 42–46 [40]). Such resistance notwithstanding, especially in the interwar period, the new areas and technologies—in particular, the inspection of motor vehicles—gained increasing importance; thus the steam boiler associations changed into safety standards authorities. About one year before the Nazi regime triggered World War II and thus began to deploy the destructive forces of technology in new and unknown dimensions that put millions of people at risk and to death, the federal minister of economic affairs reorganized the technical safety inspection system when he transferred the powers of regulation from the states to the Reich and officially transformed the steam boiler associations into state-regulated but self-governed safety standards authorities (Wiesenack, 77–92 [40]).

Thus, if we focus only on the German case, we can see that in the nearly 70 years from the unification of Germany in 1871 to the advent of World War II (WWII) the danger from accidents of technological artifacts and installations that were prone to explode, to cause fire, or to go out of control gave rise to the establishment of a still-important field of risk management. To be sure, the participants in this development hardly used the term risk prior to the second half of the last century. Nevertheless, they developed regulations, strategies, and routines for coping with a new class of human-made dangers: technical risks. One way to accomplish this task was to broaden the field of technical knowledge. Therefore, the associations collaborated with technical universities (or they even established their own research

laboratories, as the Bavarian steam boiler association did in 1904 under the direction of the eminent inventor, engineer, and industrialist Carl von Linde—The Steam Research Laboratory, cf. Wiesenack, 22–23 [40]). Furthermore, the associations not only conducted inspections, but also worked as consultants. They participated in developing norms of technological safety and pushed for safety improvements (Wiesenack, 73–74 [40]). Whereas the steam boiler inspectors' notion of risk was confined to the likelihood of failure of technological equipment, this notion became broader after World War II, when the safety standards authorities in Germany and elsewhere extended their domains, as they included dangers that resulted not from failure but from "normal operation" of technology. This new awareness of dangers emerged with the spread of large technological systems (Perrow [30]). Safety standards authorities, however, were politically unsuccessful in establishing legally binding safety norms for the design and use of technology. These legal constraints worked as a strong impetus toward the development of risk analysis because the assessment of risks was to supersede legally inadequate regulations via safety norms (Lukes [25]). But until today it is an open question in engineering, whether probabilistic calculations are superior to safety margins or not (Doorn and Hansson [54]).

3.2 Managing Health Risk: City Sanitation and the Coalition of Experts and Stake Holders Against the Cholera Threat

The introduction of new technologies was not the only source of new perils to industrial society. Industrialization itself led to rapidly growing cities, which in turn exposed people to more danger, as the likelihood of epidemics spreading from crowded quarters with poor living conditions, lack of adequate public sanitation (i.e., human waste management), insufficient water supply, and high pollution in even remote and wealthier waterways and neighborhoods grew (as a pioneering study see Simson [37] and more literature in Labisch and Vögele [72]). In the time span from 1831 to 1892, the northwest of Europe was struck by four waves of cholera epidemics with a death toll of 50 percent of all men and women who fell ill. (Because of increasing "globalization" of commerce and emigration, the United States experienced an equal number of cholera epidemics over the same seven decades. For the US see the eminent book of Rosenberg [85] and for Hamburg see Evans [57].) In fighting this danger, European city authorities, in collaboration with technical and medical experts (i.e. engineers and doctors), developed increasingly successful strategies of risk management. In local politics, engaged hygienists—a new, interdisciplinary oriented group of experts—took up the issue of city pollution as a health problem and established coalitions of local politicians, businessmen, engineers, doctors, and other experts. These coalitions mobilized knowledge, experience, and competencies from various fields in order to advise municipal authorities on appropriate solutions for their city's sanitation and improved public health. In Germany, the Frankfurt doctor and local politician Georg Varrentrapp (1809–1886)

decisively shaped the coalition of experts when he established the German Association for Public Health in 1873 (Hardy [64]). Among the first 230 members, there were 20 mayors of big cities (Berlin, Frankfurt, Munich, Danzig, . . .) besides other municipal authorities, 112 physicians, and a wide range of architects, engineers, entrepreneurs, chemists, pharmacists, journalists, as well as famous hygienists from abroad. Meetings of the association provided a forum to negotiate core problems of city hygiene and public health among the interdisciplinary group of experts. Participants gave lectures that were extensively discussed by all members. The aim was to find common ground between the medical, technical, and financial arguments. Via majority vote the association settled its negotiations and thus established a base of knowledge for enabling municipal authorities to take decisions on appropriate sanitation systems. With such mobilization of experts from different fields, as well as engaged and concerned citizens, local authorities and stakeholders of various kinds accumulated and disseminated knowledge and evaluated alternative strategies for reducing the risk of an epidemic's outbreak. Thus, the protagonists of the 19th-century hygiene movement invented a pattern of risk management that enabled the hygienist activists to push decision-making in favor of sanitation systems, although the question as to the causes of infectious diseases was not yet settled (Hardy, 108 [64]).

3.3 Regulating Food Risk: The Introduction of Science-Based Food Control

In the mid-19th century complaints about food adulteration and consumer fraud began to make headlines in the press of industrial countries. The range of new food products on the markets stemming either from imports or from innovations of industrially processed food challenged the experience-based knowledge not just of consumers but also of food merchants to make judgments on food quality (Zachmann and Østby [41]). A remarkable percentage of these product innovations and product changes were initially perceived as adulteration, and this caused heightened uncertainty at the food market. Because inadequate food supply can easily result in political unrest—many German cities experienced bread riots on the eve of the 1848 Revolution—national legislators strove to establish an infrastructure for food control through enforcing nation-wide food laws that were to supersede local regulations.

Great Britain pioneered the development. In 1860 Parliament enacted a landmark food law aimed at preventing adulteration of all food and drink. (For more details see Clow and Clow [49], Wohl [100], Smith and Phillips [91].) The German empire followed in 1879, and between 1890 and 1906 national food laws were enacted in Belgium, Austria, Switzerland, France and the United States. These laws, however, provided just the framework of food controls, and had to be supplemented with food standards as benchmarks for proving food quality. But who was to define food standards? Practitioners of the food business claimed to have the last word on how to secure food quality and food safety, and they for the most part showed limited

interest in collaborating with experts such as chemists, hygienists, or doctors. The chemists developed more and more interest in food chemistry as the chemical analysis of food promised to become a rewarding field for exploiting professional expertise. Thus, chemists pushed chemical analysis and employed the nutrients paradigm for determining food standards and subsequently food quality (Spiekermann [93], Dessaux [51], Hierholzer [65]). National legislators again faced the task of reconciling the interest of the food industry in liberal markets with consumers' demand for safe food and the states' interest in public health and political stability. Thus, national food legislation at the turn of the 20th century gave rise to nationally slightly different systems of food control in order to manage food risk (Spiekermann [93]). At the same time, however, hygienists and chemical experts pushed for an international approach toward food regulation (Dessaux [51]). In September 1907, La Croix Blanche de Genéve was created as an international association, based in Paris, specifically in order to fight food fraud and adulteration. The association organized two congresses, the first in Geneva in 1908 and the second in Paris a year later. Then it petered out. In spite of its short life and the fact that it took the Codex Alimentarus, its successor, almost half a century to get established, the association had a great impact on food safety regulation. It strengthened the authority of chemical expertise in the food market, as the association's organizers had managed to reach agreement on a broad catalog of food definitions. These definitions provided the fundamentals of food evaluation based on chemical analysis. Thus, at the turn of the 20th century, food risk management was established as food regulation, and subsequent food regulation based on food standards became established in a tense collaboration of chemical experts and food industry representatives. The institutions established in the late 19th and early 20th century have continued to be the primary institutions dealing with food safety, even as the globalization of food supply has raised many questions about food safety.

3.4 Capitalizing Risk and Enhancing Social Security: The Emergence of Insurance as Catalyst of Modern Strategies Toward Risk and Security

Whereas the aforementioned strategies of risk management aimed at preventing individual and societal harm from technologically produced hazardous products and environments ranging from steam engines to crowded cities and food adulteration, the advancing insurance system of the nineteenth century promised to compensate persons harmed, the survivors of deceased victims, and the owners of damaged property. Modern insurers, who had severed their business practices from gambling, now capitalized on risk, as they sold their customers no longer chance but a new degree of control over uncertainty through empirically established probabilities. Hence, risk became a new commodity.

Insurance companies that, in the modern sense, offered contracts with mathematically calculated premiums and a legal claim on the indemnification payment

were founded at first in London. The Amicable Society (est. 1706) pioneered the advance, as the world's first life insurance company, but operated at first more as a friendly society than as a business. The Amicable, however, induced a rejected applicant who was a mathematician to establish the Equitable Society in 1762. As the world's oldest mutual insurer the Equitable owed its success, as we learn from Daston (175 [11]), to "its exploitation of the regularity of the mortality statistics and the mathematics of probability to fix premiums [. . .], but also. . . [to] its creation of an image of life insurance diametrically opposed to that of gambling".

From the early 19th century a whole range of new insurance branches emerged that signaled where witnesses of industrialization and urbanization perceived new, potential threats to their bodies, businesses, and property and thus felt compelled to make provision for such contingencies. In Germany, for instance, private entrepreneurs insured against the risk of transport damages on the Rhine river traffic (1818), the risk of harm by railroad accidents (1853), injury by broken glass (1864), damage from broken taps (1886), and losses caused by mechanical breakdown (1900). Furthermore, in 1829 the first reinsurance business was established, and in 1875 personal liability insurance was set up (Koch [71]). While in all these cases private entrepreneurs developed a need for more safety as a chance to earn money, nation states also detected the potential advantages of the insurance trade. In contrast to the fund-seeking politics of early modern states that sold annuities for getting the sovereign money, nation states sought to utilize modern insurance in order to provide for political stability via social security systems. The founder of the German empire, Bismarck, pioneered the institutionalization of state compulsory insurance, i.e. social security, as well as health and accident insurance (Ritter [84]). As soon as the states enacted compulsory forms of insurance, provisions for mitigating risks became a pillar of the welfare state (Ewald [13]).

The enhancement of risk policies, together with the enormous extension of the insurance system throughout the long 19th century, necessitated the accumulation of knowledge and experience on how to assess and to manage risks. For insurers this was of critical importance, as the success of their business stemmed in large measure from such knowledge. The first insurance branch to develop and apply theoretical knowledge was life insurance. Insurers could build upon the well-developed classical probability theory and upon mortality statistics. Therefore, it came at little surprise that in Great Britain in 1848 the Institute of Actuaries was founded (Pabst, 26 [29]). In Germany, however, insurers had been much more reluctant to develop an interest in scientific knowledge. Only at the turn of the 20th century did some German universities, such as Göttingen, Leipzig, Frankfurt am Main, and Cologne, and Technische Hochschulen, such as Dresden and Aachen, set up study courses related to the insurance business. Göttingen was the first to establish a "seminar on insurance science" in 1895 (Pabst, 26–29 [29]). Insurance science, however, was not a coherent field of knowledge but a conglomerate of many special fields. The theoretically most advanced and exacting field was actuarial mathematics, which is first and foremost probability theory. Actuaries, however, were employed only in the life insurance area until well after 1950, as Reinhard Pabst has shown in his dissertation (Pabst, 116–118 [29]).

Except for life insurers, practitioners in the insurance business proved to be quite averse to theoretical approaches to risk calculation. One main reason was the lack of appropriate statistical data. Another reason was economic success based on more traditional methods. Empirical knowledge and experience remained very important for estimating risks and insurance premiums. For example, even as late as the mid-20th century, maritime insurers would gauge, as their predecessors in 16th century Venice had done, "the integrity of the ship-owner, the skill of the ship's officers, [and] the quality of the crew" (Pfeffer, 69 [31], Gigerenzer, 257 [19]).

Pabst's study on machine insurance reveals that insurers did not put much emphasis on more elaborate risk assessment for improving premium calculations but preferred to make provisions for damage prevention by increasing the availability of new technological knowledge. Allianz, the largest supplier in this field, published a journal called "The Mechanical Breakdown" to teach strategies of how to avoid breakdowns. Furthermore, the insurer organized company inspections, better turbine control procedures, and manager training classes, and set up its own materials-testing institute and museum. With such measures, insurers of technological risks developed a new domain of employment for engineers (Pabst, 52–79 [29]).

The increasing availability of technological knowledge notwithstanding, experts in the property insurance business began to articulate a need for more theoretical knowledge by the end of the 1920s. Founded in 1935, the German Association of Actuaries put the development of mathematics for the property insurance business on the agendas of its congresses in subsequent years. Thus, expectations grew that probability theory would begin to be applied beyond life insurance for the analysis of uncertainties and the identification of risk in property and indemnity insurance (Pabst, 80–97 [29]). A first mathematical model for non-life insurance, however, had been presented by the Swedish actuary Filip Lundberg in 1909. It was largely ignored until the Swedish professor Harald Cramér from Stockholm University built his insurance risk theory based on Lundberg's approach. Even Cramér's risk theory was slow to be used; only well after World War II did the insurance industry widely adopt it, albeit the first publication dated from 1930 (Pabst, 52–53 [29]). This delay reveals that practitioners paid little attention to the ambitions of actuaries, and with the outbreak of World War II all priorities changed anyhow. General diffusion of actuarially based risk theory in non-life insurance was delayed until the international community of actuaries established the Actuarial Studies in Non-Life Insurance (A.S.T.I.N.) organization in 1957. Establishment of this organization proved to be an important step for the diffusion of probability theory in non-life insurance, even if the transition from actuarial theory to practice took longer and diffused at different rates in the various branches of property and indemnity insurance (Pabst, 126–130, 165–193 [29]).

The extension of the insurance business increased risk awareness, and at the same time promoted research as to the causes and the prevention of risks. This was true not just for the aforementioned property risks due to technological breakdowns, but also for health risks caused by industrial accidents. When national governments in many countries, following Bismarck's pioneering example, began to insure workers against industrial accidents, research in industrial medicine received a tremendous

boost. Physicians who worked for the state in compulsory health and accident insurance developed industrial medicine. The subject area of the newly emerging field was the detection and prevention of health risks and risks of accidents in industrial work places (Lengwiler, 146–148 [23]). The physician's task to provide insurers with medical certificates as to the causes of damage to insured workers' health boosted research on medical causalities. Up to the interwar era of the 20th century, medical causality was discussed most in bacteriology. Here Robert Koch's and Louis Pasteur's explorations of tuberculosis and anthrax as bacteriologically caused diseases gave rise to a mono-causal, deterministic concept of disease that replaced manifold etiologies (Schlich, 8 [87]). But with the more frequent appearance of particular diseases in specific industrial environments, such as silicosis or various kinds of cancer, mono-factorial chains of causes did not work. Therefore, in the interwar era, industrial medicine gradually began to abandon strictly deterministic concepts of causality in favor of probabilistic health risk research.

As Martin Lengwiler has shown in his study on the development of accident insurance in Switzerland from 1870 to 1970, probabilistic concepts gained ground particularly in the emerging field of toxicology (Lengwiler, 149–158 [23]). An important figure in this field was the director of the forensic institute at the University of Zurich, Heinrich Zangger (1874–1957). Poison gas attacks in World War I, as well as high incidence of poisoning from wartime-promoted chemical substitutes, inspired him to deal with military as well as industrial poisoning. With improved measurement methods based on new instruments, he began to use a statistical approach to evaluating the effects of poisons on human bodies. Thus he paved the way toward probabilistic diagnoses. Zangger defined industrial medicine as a "science of danger" aimed at control and prevention by describing potential dangers of industrial and technological environments. Zangger's concept of a science of danger stands for an early approach toward an independent and theoretically ambitious discipline of medical risk research (Lengwiler, 152 [23]). Toxicology as pioneering medical risk research was to determine the risk of poisoning emanating from human exposure to dangerous materials (Hounshell and Smith [67]). During the 1930s toxicologists introduced threshold value definitions under the heading of "maximum acceptable/allowable concentration" (MAC) of hazardous materials in workplaces (e.g., exposure of workers to a range of organic chemicals used in the manufacture of synthetic dyes). In 1933, industrial physicians within the Soviet public health system had been the first to succeed in getting MAC-values enacted into law. US industrial medicine changed to MAC values in 1937. Other countries followed after WWII. The West German Association for Industrial Safety set up a MAC committee in 1954 (Bächi, 421 [42]). Just one year later the senate of the German Research Council established a commission on materials with adverse health effects in workplaces as an advisory body for government authorities (Bächi, 422 [42]). The enactment of MAC-values as litigable criteria in accordance with insurance law signified a shift toward risk assessment based on probabilistic concepts with a statistical understanding of causality in industrial medicine (Lengwiler, 155 [23]). The statistical understanding and probabilistic assessment of health risk in industrial medicine proved to be a useful and enduring point of departure for the development in social

and preventative medicine that began in the interwar era but gained momentum only in the post World War II era (Lengwiler, 155–158 [23]).

3.5 Controlling Quality via Statistics: Quantitative Approaches to System Safety and Reliability in the Bell Telephone System

Whereas the insurance trade pioneered the quantitative understanding of risk, problems of electrical engineering gave rise to quantitative approaches to system safety and reliability that were to constitute an important building block for the emergence of Probability Risk Assessment (PRA) in various fields of complex engineering systems, and thus they contributed decisively to the evolving intellectual core of scientific risk research. Both, the increasing scale of mass production and the growing size, complexity, and interdependencies of large technical systems challenged the hitherto common ways of assuring the safety and reliability of those systems. Because the reliability of a technical system depended on the manufactured quality of each part, it soon became clear that quality control for the millions of components in these rapidly expanding systems would become a bottleneck for warranting the safety and reliability of those systems. American Telephone and Telegraphy (AT&T, owner of what was simply called "the Bell system" until 1984) was the first company to tackle this new challenge. In the second decade of the 20th century the company concluded that future growth depended on the geographical extension of telephone service (Miranti, 51 [78]). To meet this challenge the company had to improve transmission quality. One way for quality improvements led through innovations in the quality inspection regime. George A. Campbell, a MIT and Harvard trained electrical engineer who also studied advanced mathematics under Felix Klein in Göttingen and electricity and magnetism under Ludwig Boltzmann in Vienna, pioneered the introduction of probability-based techniques in the Bell system for positioning loading coils on transcontinental telephone lines. Around 1924 he strongly encouraged his colleagues to also use probability theory in confronting uncertainties related to management problems (Miranti, 55–56 [78]). A pioneer in industrially applied probability theory, Campbell called for developing a common knowledge base—industrial mathematics (Campbell [47]). As early as 1925 Bell Telephone Laboratories did indeed follow this advice: they established a Mathematical Research Department, headed by applied mathematician Thornton C. Fry, who in 1928 published his widely received text, Probability and its Engineering Uses [16].

Bell Labs' research statistician, W.A. Shewhart, recognized the usability of statistics as a scientific approach toward improving the quality control regime of the company's equipment manufacturing operations. He suggested analyzing product-defect distributions with the help of the properties of the bell-shaped normal (i.e., Gaussian) curve. According to Miranti, Shewhart "defined manufacturing control in terms of acceptable levels of variance, measured in standard deviations, from the mean number of deviations in a product lot" (Miranti, 60–61 [78]). This proved to

be the decisive point of departure for the subsequent development and introduction of Statistical Quality Control (SQC) in the Bell system—and eventually beyond it (Shewhart [36]). With the advent of the Great Depression, when AT&T's labor force shrank and manufacturing inspection teams dwindled, the company recruited more graduates with strong mathematical backgrounds. This boosted the full exploitation of SQC in the Bell system's factories and elsewhere in the company's operations (on the history of SQC see also Juran [70]).

Not only in the US but also in Germany SQC came into being in the inter-war period. Here, Karl Daeves, the head of the research laboratories of the Rhenish Steelworks, developed the method of SQC to control variations in steel production. Daeves called his method "Großzahlforschung" (large number research) and praised it as a way to replace the "doubtfully intuitive information that is based on subjective experience, by statistical values of objectified experience" (Daeves [8]). Via an analysis of frequency distributions with the help of probability graph papers that Karl Daeves developed together with the food chemist August Beckel in the early 1930s, these industrial researchers laid much of the groundwork for the use of probability theory in industry (Daeves and Beckel [9]). In Germany and the US alike the method of Großzahlforschung received the most attention in the electrical industry. Industrial researchers of the German electric light bulb producer Osram and the giant of the electrical industry Siemens collaborated with well-known professors from the Technische Hochschule Berlin in a lecture series on SQC during the winter term of 1928–1929 and again at the beginning of 1936. The Nazis hampered these fruitful beginnings when they forced leading practitioners and promoters of industrial mathematics, and mathematical statistics especially, to flee from the anti-Semitic regime (Tobies, 190 [39]). In contrast to Germany, the US state encouraged industrial mathematics when the National Defense Research Committee established the Applied Mathematics Panel (AMP) at Columbia University in 1942. As an appointed member of AMP, the Romanian-Austrian mathematician Abraham Wald (1902–1950) developed the statistical technique of sequential analysis in 1943. An important development in SQC theory and method, sequential analysis allowed reduction in the number of random samples necessary to maintain quality control in armaments production, thereby increasing manufacturing productivity and saving the US state a lot of money (Morgenstern, 183–192 [26]).

The multiple efforts to develop SQC paved the way for the new profession of quality engineering. During World War II, Bell engineers transferred knowledge of SQC to war industries, and the US Department of Education and the War Production Board set up training courses. By 1946 the number of newly trained quality engineers had reached a critical mass, which resulted in professionalization; that is, the American Society for Quality Control was founded in 1946 and more than 2000 professionals attended the organization's first technical conference in 1947 (Miranti, 67 [78]). In postwar Europe quality control was pushed via the Marshall Plan and subsequent recovery programs. The largely US-funded European Productivity Agency initiated the establishment of the European Organization for Quality Control in 1956, which was allied with the American Society for Quality Control. In the same year the German journal "Qualitätskontrolle" appeared for the first time. It

changed its title into "Qualität und Zuverlässigkeit" (quality and reliability) in 1970 (Masing, 411–415 [74]).

Growing imperatives for reliability in weapons systems during the Cold War arms race led to further extensions of probabilistic quality control and gave rise to Reliability Engineering and quantitative reliability analysis. For example, in the early 1950s the US Department of Defense commissioned a study on how to increase the reliability of one of the most ubiquitous but also most failure-prone components of military electronics—the vacuum tube (Stott et al. [94]). Issued in 1957, this so-called AGREE (Advisory Group on Reliability of Electronic Equipment) Report furthered the development of quantitative reliability analysis and constituted an important building block for the emergence of Probabilistic Risk Assessment (PRA). It will come as no surprise that electrical engineers, who were well-grounded in probability theory, contributed significantly to this development.

4 Hot and Cold War, Large Technological Systems and Safety Concerns: Tackling Uncertainties via New Knowledge and Methods of Assessing Risks

The World War II experience changed people's attitudes toward risk and uncertainty in quite contradictory ways. Having survived the Second World War and the deadly Nazi regime, some people emerged with confidence that contingencies could be controlled and the world changed for the better. Economists claimed to apply the right instruments to stabilize the equilibrium of markets. Keynesianism promised full employment. Bretton Woods re-established the stability of the gold standard of the 19th century. The International Monetary Fund and the World Bank promised economic advancement for the developing world. The United Nations was set up to secure peace and progress around the world. Engineers lined up not just to do away with the enormous destruction and rubble of the war but also to improve the safety of technology. With the development of more and more large and complex technological systems, the tasks of improving systems' reliability—and thus of increasing safety—triggered new approaches to risk management. Governments strove toward political stability based on improved welfare systems and the transition toward mass consumption. This also included the responsibility that was felt on the part of the governing parties and administrations to protect populations from environmental, health and technological risks. Since the 1950s national legislation enacted new regulations, e.g., Food Additive Amendments to improve food safety, regulations for radiation safety, and new laws to increase highway and motor vehicle safety.

Thus, we find an ambivalent situation in the first two decades after the war. There was, on the one hand, great confidence that uncertainties could be controlled and risks assessed. This confidence was based on the assumption that everybody would behave rationally, an assumption that proved to be fertile ground for the spread of

new concepts and methods to deal with future uncertainty. One of those methods was game theory, developed by the eminent mathematician John von Neumann and economist Oskar Morgenstern prior to and during World War II (von Neumann and Morgenstern [27]). Game theory became a highly used analytical tool during the Cold War, and major developments proceeded as its use spread, the Nash equilibrium being perhaps the most important. By the end of the Cold War, game theory had come to dominate scholarship in economics and had spread to many areas where analysis of present and future decisions in contexts of uncertainty must be made.[3] On the other hand, increased confidence went together with an increased awareness of and greater attention to potential dangers and perils. And there was good reason for increased concern, as the war had brought into being technologies with hitherto unknown potential dangers. One case in point was nuclear technology.

4.1 Nuclear Technology as New Challenge to Deal with Problems of Safety and Risk

When US President Dwight D. Eisenhower announced the decision of his administration to promote peaceful uses of atomic science and technology on an international scale in his famous Atoms for Peace speech in front of the United Nations' General Assembly on December 8, 1953, nuclear-fuelled power plants ranked high on the agenda of desirable peaceful applications of the atom (see Eisenhower's "Atoms for Peace" Speech [80]). Consequently, the Atoms for Peace initiative prompted national governments of many countries as well as international institutions under the aegis of the United Nations and the Organisation for European Economic Co-Operation to establish programs for the use of atomic energy in many domains.[4] However, the paradoxically overheated Cold War expectations about the seemingly unlimited potential of nuclear technologies could not erase the fear—fuelled by the atomic bombs dropped on Hiroshima and Nagasaki—that the power of the atom would have lethal effects when chain reactions ran out of control and when humans were exposed to ionizing radiation from fissionable materials. Imagining nuclear accidents and estimating potential damage became a major issue as the question arose as to who would assume liability for private nuclear power plants in case of an accident. With no historical knowledge of reactor safety and with seemingly unlimited liability should a reactor blow up or "melt down", the US insurance industry was unwilling to underwrite insurance risks for private nuclear energy. This

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[3]Even a short history of game theory is beyond the scope of this chapter, but the interested reader should consult the following work: Poundstone [79]. On game theory in the Cold War think tank RAND see Hounshell, 253–255 [66].

[4]On programs to put the peaceful atom in service of food and agriculture see e.g. Zachmann [101].

refusal threatened to delay the development of Eisenhower's "peaceful atom". Thus, in 1957 the US Congress passed the Price-Anderson Act by which "the federal government provided insurance to cover losses above the \$60 million private insurers were willing to cover (under considerable federal pressure), up to a total of \$560 million" (Carlisle, 931 [6]). The government intended the law to be in force for only ten years, as it assumed that major safety improvements would occur and sufficient nuclear power plant operating data would be accumulated so that the state could withdraw and leave the field to private insurers. That, however, did not happen. Instead, the act was reinstated several times. Still in 2005 the Bush administration and Congress renewed the Price-Anderson Act as part of the Energy Policy Act of 2005 and extended it for the hitherto longest period of 20 years till 2025 (Price-Anderson Amendment Act [81]).

But how did engineers think about risk? Here two approaches had been prevalent, a deterministic and a probabilistic approach. The difference resulted from different engineering cultures. Chemical engineers from Du Pont who designed and built the first three plutonium production reactors at Hanford, Washington, took the deterministic approach. They explored potential component failure step by step and sought to determine what precautions needed to be taken to prevent such failure. In this approach, any effort to pre-calculate the mathematical probability of a component failure was completely absent. But as soon as the electrical engineers entered the nuclear power field in bigger numbers—US Admiral Hyman Rickover's Naval Reactor Program had opened the door—the probabilistic approach toward reactor risk gained ground. It was based in the electrical engineers' culture, as they saw the reactor as a product that "they fully thought out and put on paper before construction began" (Carlisle, 928 [6]). In this process, they calculated the probability of failure of crucial components. Increasingly available digital computer power increased the feasibility of such calculations. Thus, PRA in engineering emerged out of the professional culture of electrical engineers.[5] The two ways of thinking about risk set different priorities. Whereas deterministic engineering put physical problems and their remedies center stage but did not pursue any quantification, probabilism evaluated the reliability of entire complex systems as it calculated or estimated the likelihood of failure of crucial system's components.

The electrical engineers who introduced probabilistic methods into reactor design were able to build on an early tradition of probabilistic approaches that had already found fertile ground in the Bell system in the first half of the 20th century. Teachers such as Ernst Frankel also guided the electrical engineers. He taught at the Massachusetts Institute of Technology and wrote a textbook for a course on systems reliability that applied probabilistic thinking to complex systems (Carlisle, 926 [6]). He did what engineers and mathematicians at Bell system and elsewhere had envisaged since the 1920s when they explored the possibilities of applying probability theory to practical engineering problems (see e.g. Fry [16]).

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[5]See the paragraph on SQC above.

4.2 Safety Engineering in the Aerospace and Defense Sector: Pioneering New Methods of Risk Assessment

Besides reactor design it was the aerospace and defense sector that fostered the application of probabilistic methods in safety engineering (Rip, 4 [83]). Beginning in the early 1960s fault trees became a commonly used technique that was applied for the first time in safety evaluations of the Launch Control System of the US Minuteman ICBM (Ericson [55]). Fault Tree Analysis is grounded in reliability theory, Boolean algebra and probability theory. The framework of FTA for analyzing very complex systems and complex relationships between hardware, software, and humans is comprised of a basic set of rules and symbols. FTA's initial development is ascribed to Bell Labs' researcher Hugh A. Watson who graduated with a PhD in nuclear physics from MIT in 1949 and worked at Bell Labs afterwards. In 1961 Watson conceived of FTA in connection with a US Air Force contract to perform the above-mentioned study of the Minuteman Launch Control System (Ericson, 1 [55] and Haasl, 1 [63]). Boeing Aircraft Company engineer David Haasl recognized the value of Watson's new method and organized the application of FTA to the entire Minuteman Missile System. Other departments of Boeing got interested as well, and Boeing began to use FTA in the design of commercial aircraft. In assigning probabilities to the events or component failures involved, the aerospace engineers aimed at calculating the overall probability of system failure in advance of use. In 1965 Boeing collaborated with the University of Washington in holding the first System Safety Conference. The rapid spread of FTA, however, stemmed mostly from the fact that it emerged in the very heated Cold War context of nuclear weapons systems development. Relying upon a policy called Mutually Assured Destruction (MAD) from the ever-growing number of atomic and thermonuclear weapons, the US believed the new Cold War imperative was to control systems safety of its increasingly potent weapons delivery systems. Already in 1950 the Air Force had established a Directorate of Flight Safety Research that was to be followed by a safety center of the Navy in 1955 and the Army in 1957 (Ericson [56]). In the late 1950s system safety began to be perceived as a new engineering discipline. That the military was its midwife became obvious with the publication of a document entitled "System Safety Engineering for the Development of United States Air Force Ballistic Missiles" in 1962 (Dhillon, 265 [52]). FTA's primary contribution to this development was its probability-based quantitative technique for analyzing system safety and reliability of space and defense systems. Improved FTA methods were developed, thanks to advances in both statistics and digital computer applications (Ericson [55]). The Department of Defense soon built FTA into specifications for all its weapons systems development contracts.

In the midst of the first wave of FTA-hype, however, the National Aeronautics and Space Administration (NASA) refrained from quantitative approaches to risk and safety analysis. John Garrick, a pioneer in nuclear risk assessment and a leading figure of the US risk analysis community, has retold the events as follows: "The time is remembered as about 1960, and the event was a bad experience with a probability calculation on the likelihood of successfully getting a man to the moon

and back. The calculation was very pessimistic and embarrassing to NASA officials and soured them on the utility of probability calculations. From that point forward, NASA chose not to do probability, that is, quantitative risk and safety analysis, on their space systems. Rather, they adopted a qualitative approach utilizing Failure Mode and Effects Analysis (FMEA) as the principal building block for their risk analysis program" (Garrick, 1 [60]. For information on Garrick see Profile [82]). Only after the Challenger accident on January 28, 1986, did NASA re-visit its earlier decision and integrate quantitative risk assessment into its systems safety management processes (Garrick, 3–7 [60] and [18]). Meanwhile, however, NASA's preference for the qualitative FMEA concept pushed its development and made the qualitative approach toward systems safety attractive to other circles. The automobile industry took it up in the late 1970s when the Ford Motor Company adapted the method after the Ford Pinto debacle in which the company's hitherto unremarkable small car had to be recalled because of safety concerns related to the location and integrity of its gas tank (Tietjen and Müller [95]). From the automobile industry FMEA spread to other branches, became more diversified methodologically, and eventually developed as a risk-mitigating tool that became a standard element of prevention strategies.[6] The food industry developed its own version of FMEA even before the automobile makers when, during the Apollo moon program, NASA established new safety requirements for the astronauts' diet. The food company Pillsbury was the prime contractor for the space food program and adapted military experiences of critical control point (CCP) identification and FMEA into what became known as "Hazard Analysis and Critical Control Point System" (HACCP) for food safety in the early 1970s (Sperber and Stier [92]).

By no means did NASA's initial rejection of probabilistic risk assessment in favor of more qualitative approaches to safety result in any serious setback for Probabilistic Risk Analysis. By the late 1960s and early 1970s PRA was moving swiftly toward broad acceptance, thanks especially to developments in the nuclear sector. In turn, the perceived success of PRA boosted the professionalization of risk research and risk communication.

4.3 The Rasmussen Reactor Safety Study as Contested and Yet Celebrated Breakthrough of Probabilistic Risk Assessment

A decisive event in this process was the Rasmussen report, a reactor safety study that made extensive use of fault tree analysis and probabilistic techniques for estimating and quantifying risks (Rasmussen [33]). In 1972 the US Atomic Energy Commission (AEC) set up a new panel, headed by MIT engineering professor Norman R. Rasmussen, to evaluate the safety of nuclear reactors. The new head of the embattled AEC, James Schlesinger, aimed at presenting the AEC as a referee between the

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[6]On FMEA and FTA as methods to increase dependability in engineering systems today see Vogel-Heuser and Straub in this book.

nuclear industry and an increasingly concerned public; therefore he strove to mitigate heightened safety concerns (Walker, 41–41 [96]). The latter had been voiced, e.g., by the recently founded Union of Concerned Scientists, which criticized how the AEC had dealt with unsettled questions about deficiencies in emergency core cooling systems in the AEC's licensing procedures (Walker, 33 [96]). More safety concerns arose as a result of the growing environmental movement, especially concerning thermal pollution, the effects of low-level radiation from routine operation of nuclear power plants, and the risks posed by high-level radioactive waste storage and disposal. Thus, the Rasmussen panel's task to assess accident risks in US commercial nuclear power was bound up with high expectations on the part of the AEC. The study was to demarcate the field the AEC felt responsible for—reactor safety—in advance of the pending renewal of the Price-Anderson Act (Carlisle, 931 [6]). When in October 1975 the US Nuclear Regulatory Commission (the AEC's successor regulatory agency) presented the final Rasmussen report to the public, the report immediately won a lot of attention. This was largely due to its scale and political significance, but also to its extensive use of probabilistic techniques. It must be stressed, though, that the Rasmussen report was by no means the first study to apply probabilistic approaches in the assessment of technical risks. As already noted, physicists, electrical engineers, and aerospace engineers had done so earlier to varying degrees and in various contexts (Carlisle, 933 [6]). Nevertheless, the Rasmussen report made a pioneering contribution because it introduced a general public of non-specialists to the application of probabilistic techniques in reactor safety studies based on fault trees and other forms of probabilistic risk analyses. Furthermore, the Reactor Safety Study made use of Monte Carlo simulations that had come into being in the context of the development of thermonuclear and enhanced fission weaponry as a kind of lingua Franca among physicists, nuclear theorists, chemists, electrical engineers, mathematicians, statisticians and others for dealing with problems of mutual interest: nuclear atomic structure, molecular structure, equilibrium calculations, reaction rates, resonance energy calculations, shielding calculations, and the fitting of decay curves (Lee, Grosh, Tillman, and Lie, 198 [73]).[7] Monte Carlo simulation has become standard fare across a wide number of science, engineering, and social science disciplines and also in industries and the finance and insurance business.

Despite its achievements the Rasmussen report also received serious criticism. The Union of Concerned Scientists pointed to the fact that fault tree analyses had been developed in order to compare risks and to make decisions within the design process. Fault trees, it argued, were not suited for determining exact numerical probability data of accidents (Ford, 23 [14] and Öko-Institut, 18 [28]). Serious criticism was also uttered over the report's way of presenting risk. In order to guide the risk perceptions of the public, the Rasmussen report developed numerical measures to compare accident risks of reactors to more socially familiar risks, such as traffic accidents, dam breaks, and catastrophic fires. In doing so the Rasmussen panel introduced the criterion of acceptable risk, as it assumed that risks of nuclear reactors

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[7]For an excellent historical interpretation of Monte Carlo simulations (see Galison, 689–780 [17]).

which lay within the range of risks of other technical systems—to which people had grown accustomed already—would be as easily accepted (Carlisle, 934–935 [6]). Not just the public but also internal staff from the Nuclear Regulatory Commission voiced serious doubts about the results of the Rasmussen report. In January 1979 the NRC went so far to issue a statement withdrawing its full endorsement of the report's executive summary (Walker, 49 [96]).

When on 28 March 1979 a serious accident at the Three Mile Island II nuclear power plant near Harrisburg, Pennsylvania, occurred that the Nuclear Regulatory Commission had not thought to be possible, the USA encountered a severe setback for the public acceptance of nuclear energy. The nuclear establishment responded to the TMI accident with a series of measures, such as, e.g., the setting-up of a database and reporting system for accidents and the introduction of PRA as part of the documentation in pending plant applications for licenses. Thus, PRA gained more ground, despite the initially harsh criticism of the Rasmussen report and even though the occurrence at TMI had proved that heavy reliance on fault tree analysis was inadequate for the assessment of nuclear accident risks. The NRC, e.g., subsequently required PRA as part of the licensing procedure for nuclear power plants (Walker, 51 [96]).

The Rasmussen report worked as catalyst of Probabilistic Risk Assessment not just in the USA but also abroad. The Federal Minister of Research and Technology in Germany, e.g., issued the first German reactor safety study in 1976, only a year after the publication of the Rasmussen report. In the midst of the first wave of anti-nuclear power protests, the minister felt obliged no longer to rely on American nuclear safety research but to entrust the newly founded Gesellschaft für Reaktorsicherheit GRS (Society for Reactor Safety) with conducting the first German risk study on nuclear power plants that would pay attention to German characteristics, such as specific German design and safety features and especially their location in far more densely populated areas compared to US plant sites (Der Bundesminister, 1–2 [45]).[8] The first German risk study, however, closely followed the methodology of the Rasmussen report. In their Festschrift for the 30th-anniversary of the GRS, the authors praised the risk study as the first probabilistic safety analysis that inaugurated the new instrument of probabilistic safety assessment in Germany (GSR, 9 [61]). Only a few years earlier, however, probabilistic approaches had still met with resistance in many parts of Germany. In 1966, the head of the laboratory of nuclear power control and plant safety at the Technical University Munich, Professor Adolf Birkhofer, who was to become the managing director of GRS in 1977 and would keep that position till 2002, belittled probabilistic safety research as passing fashion (Radkau, 361 [32]). The mentor of Birkhofer's Habilitation, Ludwig Merz, who was an expert on measurement and control engineering and responsible for

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[8]According to Radkau, the first German research program on reactor safety was instituted by the Minister of Research and Technology only in 1971. It was triggered by the project of BASF to establish a nuclear power plant in Ludwigshafen and thus near big cities. This project was abandoned in 1972 (Radkau, 381–382 [32]).

the instrumentation of the first German-designed research reactor (FR-2 in Karlsruhe), repeatedly insisted on deterministic approaches as more appropriate or at least equally important in reactor safety research (Merz [76, 77]). As head of GRS and thus responsible for the first German nuclear power plant risk study, however, Birkhofer changed his mind and subscribed to Probabilistic Risk Assessment.

The timing for publication of the German risk study coincided with the accident at the Three Mile Island nuclear power plant. The GRS managed this situation by adding an analysis of the nuclear accident in Harrisburg, PA, as an appendix to the main study. Here the authors concluded that the events in TMI did not undermine but rather confirmed the results of the risk study (Der Bundesminister, 265–257 [45]). At the same time, however, the authors already envisioned a "phase B" of the risk study that would reveal internal safety-relevant weak points, whereas phase A had analyzed accident-caused damage outside of nuclear power plants and especially the dimension and frequency of health damage to the population (Der Bundesminister, 245–247 [45] and 6–7 [46]). Phase B was published in 1989, the same year the last two German nuclear power plants were connected to the nation's electric grid. The risk studies had not mitigated the public's safety concerns about nuclear power, and after the turn of the millennium the German government decided to abandon nuclear energy altogether.

By the mid-1980s in the US and elsewhere PRA had become, as Carlisle framed it, "part of the safety orthodoxy" and an object of Gierynian "boundary work", leading to the formation of professional risk research organizations (Carlisle, 938 [6] and Gieryn [62]). This was true not just for the nuclear sector. As we have mentioned above, after 1986 NASA returned to PRA. Also the chemical and petroleum industry developed an increased interest in PRA after major accidents at Flixborough in England, Seveso in Italy, and Bhopal in India. The Bhopal accident, especially, triggered greater activities in risk and safety research and its applications in the chemical industry (Garrick, 197 [18]). Thus, since the mid-1970s and especially during the 1980s PRA emerged as a new business. Private firms performed PRA on nuclear power plants, chemical plants, transportation systems, space systems, and defense systems (Profile, 936 [82]. The practitioners of quantitative risk assessment developed new ways of thinking about risk and safety. PRA became the intellectual core for the emerging community of risk research that began to organize itself in the late 1970s.

4.4 Swelling Uncertainties in the "Epoch of Landslide" and the Mobilization of Professionalized Research to Deal with New Risks

That reactor safety studies and PRA made headlines in the media and fired public controversies in the 1970s signalled changing attitudes toward uncertainties and risks. The post-World War II optimism that uncertainties can be controlled and transformed into calculable risks that would allow humans to make wise decisions was

superseded by new concerns because of newly emerging uncertainties. Increasing environmental concerns spread as indicated by the growing amount of readers of Rachel Carson's book Silent Spring [48] and the publication of the Meadows et al. report, Limits to Growth [75]. Growing fears of a deteriorating state of the earth stemming from industrial activities and economic growth, however, were not the only cause of concern. Wars and political unrest, uprisings and scandals in all parts of the world, reaching from the war in Vietnam via the increasingly violent conflicts in the Arab peninsula and the crushed Prague Spring up to the Watergate scandal revealed a fragile political state and the weakness of the United Nations in fulfilling its task of securing peace and progress across the community of peoples. Other forces were also unleashed. Economies crumbled when oil prices skyrocketed and the Bretton Woods Agreements broke down. In the wake of these economic storms, structural changes gathered speed, putting an end to full employment and undermining faith in Keynesianism. This was a period that Eric Hobsbawm called the years of landslide. These years historians only recently began to define as an epochal threshold, leading to an era "after the boom" (Hobsbawm, 502–720 [20] and Doering-Manteuffel and Raphael [53]). In this context, late-modern societies developed a heightened awareness of uncertainties and a changing attitude toward risks, notwithstanding the fact that fundamental anthropometric data, such as longevity and body height, and world population counts, indicated fundamentally improved living conditions in many parts of the world (on improved living conditions see Fogel [58]).

Sociologists identified the risks in late modern societies as having a new character. According to Ulrich Beck new risks result from such sources as nuclear power plants, genetic engineering, and volatile capital markets (Beck, 11 [3] and Bonß [44]). These new risks are no longer completely known nor are they fully verifiable. To a certain extent, these and other new risks remain hypothetical. Managing these risks may produce unintended side effects. In temporal, material, and social respects, the risks of the late-modern world reveal a new dimension: potential damages can no longer be compensated with money. The nuclear reactor catastrophes of Chernobyl (1986) and Fukushima (2011) may be cited as proof. Thus, new risks are no longer considered as chances that can be taken based on confidence in a basic certainty but rather as threats that should be avoided based on a fundamental awareness of uncertainty. To be sure, Beck's diagnosis of the characteristics of late-modern risks is widely known, but other authors take different, less normative, and more analytical positions (Luhmann, 13–14 [24]). The success of Beck's book, however, supports his diagnosis as a relevant description of swelling uncertainty.

Swelling uncertainties triggered a tremendous boost in risk regulation and risk research. From the end of 1960s and the early 1970s, first in the US and shortly thereafter elsewhere, there were dramatic increases in the number of agencies implementing risk-related legislation that dealt with health, safety, and environmental concerns (Covello and Mumpower, 116–117 [50]; Jasanoff, 2–3 [21]; Thompson, Deisler, and Schwing, 1334–1336 [38]). Legislative mandates to protect the environment and public health and to ensure safety furthered new federal research centers and research programs in the US and elsewhere. As more researchers than ever before in a broader array of fields began to analyze risks, they developed a need for

greater communication and interaction. Historical reports on the developing field of risk analysis underscore the importance of the 1975 multidisciplinary conference at Asilomar, CA, on the risks resulting from research on recombinant DNA molecules as one of the first meetings with risk as the main subject. The Asilomar Conference resulted in an interdisciplinary Recombinant DNA Advisory Committee that was to review all proposals for conducting rDNA research in order to prevent possible harm to human health and the environment through the unchecked spread of undesired genes (Jasanoff, 47 [69]). In 1979 another early, interdisciplinary, and explicitly risk-related meeting was organized by two General Motors Laboratory researchers as part of the General Motors symposia series under the title: "How Safe is Safe Enough?" (on the conference see Thompson, Deisler, and Schwing, 1335–1336 [38]). The conference gathered together experts from many disciplines—as diverse as anthropology and nuclear physics—and it was opened by Chauncey Starr, whose 1969 article, "Social Benefits versus Technological Risk: What is Our Society Willing to Pay for Safety", was considered by many as a landmark in risk research.[9] Thus, by the late-1970s, risk had become a subject of research that—as Sheila Jasanoff highlighted—connected disciplines as different as "mathematics, biostatistics, toxicology, and engineering on the one hand and law, psychology, sociology and economics on the other hand" (Jasanoff, 123 [68]). In their preference for either quantitative, model- and measurement-oriented approaches, or qualitative investigations as to the ethical, legal, political, and cultural aspects of risk, the researchers remained confined to the two cultures of science.[10] Jasanoff, however, did not stress the differences but the complementarity of the two cultures of risk analyses (Jasanoff, 124 [68]).

Common problems encountered across many disciplines requiring probabilistic calculation led a range of researchers to contemplate developing risk analysis as an academic discipline that would hasten the professionalization of risk research. In 1980 they founded the Society for Risk Analysis (SRA) and began publishing its journal, Risk Analysis, in 1981, which provided a forum for both debate about professionalization and new research on risk analysis. Robert B. Cumming is reputed to have been the "spiritus rector" for establishing the new society and its journal (Thompson, Deisler, and Schwing, 1336 [38]). As member of the Environmental Mutagens Society and a genetic toxicologist in the Biology Division of Oak Ridge National Laboratory in Tennessee, Cumming had been one of the participants at the Asimolar Conference and other meetings on risk research, and thus he knew the emerging community of risk analysts quite well. In the first issue of Risk Analysis, Cumming included an editorial posing the question: "Is Risk Assessment a Science?" (Cumming [7]). Cumming answered "no". Instead, he warned explicitly

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[9]The article was published in Science 165, 1232–1238. Thompson, Deisler, and Schwing, 1334 [32] praised it as providing "the basis for approaching risk issues systematically and quantitatively and (introducing) the concept of tradeoffs between risks and benefits for a wide range of risks".

[10]For an extensive and knowledge-able overview on the disciplinary perspectives on risk see Althaus, 567–588 [1].

against "dangers of professionalism" because these aspirations would serve only special interest groups but not the community of risk researchers as a whole. He envisaged the main purpose of the new society and its journal as "providing better communication among the diverse elements involved in risk management", i.e. the whole range of contributing scientific disciplines as well as political and social institutions (Cumming, 2 [7]). The author of the second article in the same issue, Alvin Weinberg, the distinguished nuclear and bio-physicist with research and policy experiences going back to the Manhattan Project, spoke on "the art of risk assessment" in order to distinguish it from science (Weinberg [98]). He pointed to strong trans-scientific elements in risk assessment, and thus referred to an idea of thinking on science and ignorance that he had developed a decade before. In 1972 he had introduced the term trans-scientific for "questions which can be asked of science and yet which cannot be answered by science" (Weinberg [97]). As examples of trans-scientific questions he named among others the biological effect of low-level radiation exposure or the probability of extremely improbable events such as catastrophic reactor accidents. Risk analysis was fundamentally important in addressing trans-scientific questions, but its practitioners could by no means claim absolute authority in offering answers.

Notwithstanding the hesitant stance of its founders, SRA both fostered and tracked many activities toward developing risk analysis into a coherent academic discipline with well-defined educational programs from the undergraduate up to the postgraduate level (Thompson, Deisler, and Schwing, 1380–1381 [38]). But the desired coherence was hard to achieve. This becomes clear with regard to the unsuccessful strivings to find a common definition of risk on which all members of the risk community could agree. In the mid-1980s, SRA tried to tackle this problem by setting up an Ad Hoc Definitions Committee that, about a decade later, finally settled the question by providing a list of definitions on the society's website without officially endorsing any one of them (Thompson, Deisler, and Schwing, 1380 [38]). Another indicator of the great diversity of the risk research community is the emergence of other, more specialized societies that are focusing on risk, such as, e.g., the Society of Environmental Toxicology and Chemistry (1979), the International Society of Regulatory Toxicology and Pharmacology (1984), the Association of Environmental Health Sciences (early 1980s), the International Society of Exposure Analysis (1989), the International Association for Probabilistic Safety Assessment and Management (1991), and the Risk Assessment & Policy Association (1994) (cf. Thompson, Deisler, and Schwing, 1347 [38]). Thus, risk research blossomed much more as an interdisciplinary rather than a disciplinary endeavor.

5 Food for Thought

The great societal transformation of the 19th century involved changing attitudes toward risk. As soon as the urban middle class of professionals and tradesmen became entitled to vote and acquired more social responsibilities, both in the public and the

private realms, they subscribed to an ethos of control and predictability and began seeking ways to avoid risks. The burgeoning economic life of the industrial revolution, however, required the entrepreneurial men of the middle class to take risks because setting up businesses involved calculating on an uncertain future. How were these contradictory attitudes toward risk reconciled in Western societies of the 19th century?

This chapter has been concerned only with developments in the Western world and has shed light on events and processes that signified shifts in concepts of risks in Great Britain, Germany, and the United States mainly. From anthropological studies, however, we have learned that culture matters in determining approaches toward risk. How do non-Western cultures experience risk, and how do these differences affect economic, financial, technological, political, and military endeavors in an increasingly globalized world?

Life insurers were the first within the broader insurance business to develop and apply theoretical knowledge to underwriting insurance policies. Practitioners in the non-life insurance trades, however, preferred empirical knowledge and experience for estimating risks and rating insurance premiums well into the second half of the 20th century, even though the Swedish actuary Filip Lundberg had published a theory of risk in 1909. Why did it take so long for probability theory to be applied in non-life insurance?

Societies developed multiple ways to deal with risks, such as developing new knowledge on dangers, imposing legally binding safety norms, developing quality and reliability engineering, requiring risk analysis of safety-critical ventures, demanding compulsory insurance for activities in danger zones, and many other measures. How did societies decide on the most appropriate means of risk management, and to what extent did professional cultures and intellectual fashions influence such decisions?

Probabilistic Risk Assessment got a boost via the Rasmussen Report, the reactor safety study that was presented to the US public in 1975. Paradoxically, the study gained acceptance only after the severe accident at the Three Mile Island nuclear power plant in 1979, although the study's calculated probability of such an accident occurring was far too low to seem plausible to policy makers and regulatory authorities. Why and how did Probabilistic Risk Assessment become an object of "boundary work" that was soon applied to many areas beyond the nuclear power sector and helped to propel forward the formation of the risk research community?

6 Summary

In this chapter we have investigated the changing concepts of and attitudes toward risk. As a point of departure, we used Luhmann's reflection on risk as future uncertainty that is caused by human-made decisions, a notion based on the economist Frank Knight's more well known concept of risk as calculable uncertainty. The questions we sought to answer were framed as follows: when did the attitude toward future uncertainties change so that our understanding of uncertainties became

narrowed down to risk? How did the modern concept of risk determine people's ways of dealing with uncertainties? How widely accepted has modern risk analysis become, in what ways has such analysis proved to be particularly problematic, and in what manner has risk analysis become professionalized?

Proto-modern notions on risk emerged in the context of the early modern rage for gambling and other forms of aleatory contracts that treated future uncertainties as a chance to make a fortune and therefore worth a wager. These aleatory contracts inspired mathematicians to develop calculations on the probable outcome of future events; thus, they began to quantify uncertainty as probability. The mathematicians' achievement, however, was incompatible with the gamblers' proto-modern understanding of risk as genuine uncertainty that precluded quantification. Therefore, the understanding of risk had to be changed before probability calculations could find acceptance as a way to manage uncertainties. The great political, technological and social transformation of Western societies ushered in this development as the attitudes toward risks now changed from something to be sought into something to be avoided—or at least managed. When bourgeois values of familial responsibility, control, and predictability began to determine the norms of society, its citizens strove to gain control over uncertainties. In this context, however, they developed a heightened awareness of a new class of human-wrought dangers and threatening uncertainties. In this chapter we have explored how steam boiler explosions, food adulteration, and cholera epidemics were not endured in fateful resignation but gave rise to modern modes of risk management. The agents of this development established regulations based on newly produced technical knowledge, formed coalitions of experts among a broad range of fields, and introduced standards of safety for technologies as well as for food. These strategies of risk management aimed at preventing individual and societal harm from human-made hazardous products and environments. At the same time, the advancing insurance system of the 19th century promised to compensate victims for their harmed bodies and damaged properties. Thus, insurers capitalized on risk as they sold their customers a new degree of control over uncertainty. As the success of the insurers' business largely depended on knowledge of how to assess and to manage risks, insurers were important promoters of research as to the causes and prevention of risks. Except for life insurers, however, practitioners in most of the other fields of the insurance trade proved to be quite reluctant to employ theoretical approaches to risk calculation.

Only after World War II did the need for a more systematic and mathematically rigorous risk analysis encourage the statistical understanding and probabilistic assessment of risks in fields beyond life insurance. Whereas the insurance trade led in developing a quantitative understanding of risk, problems of electrical engineering gave rise to quantitative approaches toward system safety and reliability that were to constitute an important building block for the emergence of Probability Risk Assessment (PRA) in the engineering fields. These developments occurred at the intersection of increasingly complex, large-scale technological systems and the establishment of formal organizations in which advanced mathematically-based science and engineering knowledge was produced and applied to those systems. We traced the quantitative approaches of system safety and reliability back to statistical

quality control in the Bell Telephone System, where it was developed beginning in the 1920s.

Formal methods of PRA emerged out of the need to determine the safety of nuclear reactors. Reactor safety became a hot-button issue when the success of Eisenhower's Atoms for Peace Cold War initiative hinged upon the acceptance and subsequent spread of nuclear power. In addition to reactor design and operation, the aerospace and defense sectors also fostered the application of probabilistic methods in safety engineering. Here Fault Tree Analysis was developed and introduced for safety evaluations of the Launch Control System of the US Minuteman ICBM; avoiding an accidentally initiated thermonuclear World War III thus served as what economist Nathan Rosenberg has termed a "focusing device" for innovation in risk research and analysis (Rosenberg [86]). As a probability-based quantitative technique for analyzing system safety and the reliability of space and defense systems, the Department of Defense built FTA into specifications for weapons systems development contracts. In order not to jeopardize its Apollo moon program, however, the civilian National Aeronautics and Space Administration decided to refrain from quantitative risk and safety analysis, adopting instead a qualitative approach using Failure Mode and Effects Analysis as the principal building block for the agency's risk analysis program. This qualitative approach toward systems safety also became attractive to other circles, such as the automobile industry and the food industry. However, despite NASA's initial rejection, PRA gained further ground and boosted the application and further development of risk research and risk communication.

As we have seen, the 1974 Rasmussen report, a reactor safety study that made extensive use of fault tree analysis and probabilistic techniques for estimating and quantifying risks, proved to be decisive for the spread and acceptance of PRA. This was the case not just in the USA but also abroad, e.g., in the Federal Republic of Germany. By the mid-1980s PRA had become an object of "boundary work", furthering professional risk research communities and spreading across the nuclear sector to a whole range of problems and applications. With more sophisticated approaches toward assessing risk, however, the awareness of new risks also increased. Since the 1980s ever more disciplines are contributing to this truly interdisciplinary endeavor, and thus are expanding and deepening the approaches to analyzing, communicating, and managing risks.

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