Chapter 11
Research in the Field of Human and Organizational Factors and, More Broadly, in Human and Social Sciences

11.1. From the consideration of human factors in safety to studies in human and social sciences

Human and Organizational factors (HOF) is a relatively recent discipline born with the technological developments of the 20th century. These factors have played a central role in most nuclear accidents. Interest in HOF is growing in the nuclear power industry, and some consider that it can increase safety more than any other discipline.

While the measures implemented in the wake of the Three Mile Island accident (TMI) focused in particular on the ergonomic and cognitive aspects of workstations, the Chernobyl accident raised questions of another kind—organizational factors. The development of a safety culture in nuclear facilities has generally been considered to be the appropriate response. This concept was described in the INSAG-4 report, published in 1991 under the aegis of IAEA, just five years after the Chernobyl accident.

More recently, the 2011 Fukushima Daiichi accident revealed the importance of societal factors in the risks governance in general.

Initial research, conducted in the 1970s, attempted to better understand human "functioning" and its impact on the performance of NPP operators and technicians not just in the control room, but also during all tasks and activities carried out (tests, maintenance, in-service inspections, etc.) outside the control room and which could affect safety. The scope of this research was subsequently extended to understanding and assessing organizational factors, then societal factors. IRSN's research also extends to methodological aspects in order to build and improve baselines and approaches for conducting its assessments.

The documents of the OECD/NEA referred to herein [1] to [10] testify to the international community's continued interest in human and organizational factors in the wake of the TMI accident.

While the very first research on this aspect in nuclear reactors began in 1977 at IPSN's Department of Nuclear Safety (influence of human parameters on safety, incident analysis methodology, human reliability, control room ergonomics), it was mainly after the TMI accident that human factors were taken into account in facility safety assessments. In the early 1980s, IPSN and EDF equipped themselves with greater resources by creating dedicated structures (French Laboratory for the Study of Human Factors (LEFH) at IPSN, Human Factors Group (GFH) at EDF). The topics of interest at the time included:

- incident analysis,
- operating staff training,
- operating procedures,
- human-machine interfaces and control-room ergonomics,
- organization of control-room staff,
- communication between control-room staff,
- the use of expert systems,
- teleoperation.

In 1989, IPSN also focused on other topics, such as:

- maintenance of France's NPPs during outages,
- operation *via* computerized procedures,
- fieldwork in maintenance.

These three topics were researched in collaboration with EDF or CNRS. The adoption by EDF of a new organization of the operation of its NPPs prompted IPSN to research this topic further.

Starting in 2003, IRSN's research increased in the frame of theses and began publishing, on topics such as outsourcing, equipment or organizational modifications in facilities in terms of human and organizational factors, etc. Outsourcing appeared to be a particular subject of concern in terms of human and organizational factors, as EDF called on many contractors to carry out work during unit outages.

In 2012, with the creation of the Human and Social Sciences Laboratory (LSHS) and the post-Fukushima period, IRSN extended its research to social aspects around the governance of nuclear risks seen from the viewpoint of organizational as well as cultural factors.

Moreover, following a number of radiation therapy accidents that occurred in France, particularly in Épinal and Toulouse, IRSN extended its research to this issue, focusing on the appropriation of new technologies and conformity management[231].

Generally speaking, a particular feature of HOF research conducted by IRSN is that it is largely based on analyses in the field (interviews, observations of projects and of work situations, such as during "sensitive" activities, etc.)—which, when these analyses are conducted as part of safety expertise, are set out in protocols established between IRSN and the nuclear installation operator. The very nature of the topics researched and the specific conditions of the assessments carried out thus provide IRSN with a cross-disciplinary and hands-on view of the maintenance, organizational and management practices at NPPs. Research may also draw on simulations, as we will see further on with the Halden Reactor Project.

Research is conducted with partners from academia, research organizations (such as CNRS aforementioned), potentially with industrial companies, and/or as part of national or international projects (such as the Halden project–see "Focus" further on). IRSN, in collaboration with AREVA and French naval contractor DCNS[232], created the Chair of Safety, Organization, and Human Research (RESOH[233]) at the École des Mines de Nantes in 2012. This five-year chair is dedicated to the management of safety in high-risk industries, particularly the nuclear industry. Moreover, in 2013, ANR decided to fund the AGORAS[234] project led by the École des Mines in Paris and in Nantes and the project led by the Center for the Sociology of Organizations of Sciences-Po on risk governance and emergency management.

A few of the most significant projects involving[235] IPSN (then IRSN), both past and current, are presented below. As we will see, this research is basically intended to understand the mechanisms behind the various activities that involve people and organizations in order to bring out, as much as possible, relevant levers to the safety of nuclear facilities.

231. In collaboration with Paris 8 University for the first topic and La Pitié-Salpêtrière hospital for the second topic.
232. French hi-tech company specializing in defense naval systems.
233. Research on Safety, Organization and Humans.
234. Improving Governance of Organizations and Networks involved in Nuclear Safety.
235. Including thesis work.

11.2. Studies and research on reactor control room design

11.2.1. The post-TMI period

A) Background

The 1970s were marked by the implementation of centralized instrumentation and control systems in industries referred to as "continuous process": iron and steel production, fine chemicals, food processing, etc. France's nuclear program benefited from these technological advances. During this decade, IPSN was confronted with the issue of analyzing the safety not only of the control rooms in France's PWRs (900 and 1300 MWe reactors), but also those in the SUPERPHENIX fast neutron reactor and the La Hague plants.

The design of the control rooms raised questions about the work of operating crews. Industrial companies thus wondered about what monitoring in the control room entailed, how information was displayed on the control room consoles, how information was passed between roundsmen and the operators in the control room, and many other aspects. Researchers in ergonomics (specialists in human-machine interfaces and human-system interactions), especially in Europe, rallied to answer these questions[236]. Their research influenced and contributed to IPSN's research.

It was in this scientific and technical context that the TMI accident occurred in 1979. TMI showed that the design of reactor control rooms plays a central role in the control of accidents, in terms of their prevention, the mitigation of their consequences and the recovery of the accident. The TMI accident was caused by a pressurizer relief valve that had remained stuck open after automatically opening to reduce a pressure peak in the RCS. This valve received a closure order, but did not close completely. However, the control interface indicated that the valve was closed because the information used by it was the order to close the valve, not its actual position—which could have been determined by a position sensor. As a result, there was confusion in the control room about the facility's actual status. Furthermore, the emergency shutdown of the reactor and the problems affecting the secondary system activated many alarms, causing the control console to light up like a Christmas tree. Because there was no way to rank the information displayed, the operating crew was quickly overwhelmed and unable to detect and extract the relevant information.

Following the TMI accident, EDF took a number of actions to improve the control rooms in its 900 and 1300 MWe reactors. These improvements were made to the control panels. The controls for functionally related equipment were grouped into color-coded areas, the main areas corresponding to overall functions were defined, and secondary areas related to sub-functions were defined within these main areas. A safety-parameter display system for controlling the reactor in emergency situations was also added to the

236. Especially V. De Keyser in Belgium, L. Bainbridge in the U.K., J. Rasmussen in Denmark, and A. Wisner and F. Daniellou in France.

control room. Other improvements were made to the organization of the operating crew. The position of "safety and radiation protection engineer" was created to independently monitor the situation from a viewpoint located away from the operating crew. The safety and radiation protection engineer makes a diagnosis of the state of the reactor (state-oriented diagnosis) whiled the operating crew uses procedures aimed at diagnosing events. The organizational logic of the operating procedures to be applied during emergency situations was changed as well (see Section Section 11.2.2 A further on).

In 1983, IPSN conducted a two-pronged study to analyze the improvement plan implemented by EDF. First, it compiled a summary of the results of research conducted on continuous processes and transposed them to the nuclear industry. Then, it conducted a study based on tests carried out on an operating simulator as part of a four-party agreement involving CEA, EDF, Framatome, and Westinghouse. IRSN used the results of these studies to issue an opinion in the improvement plan implemented by EDF.

B) Main findings from research on the operation of continuous processes

In the early 1980s, a number of studies were conducted on the activity of operators working in "continuous process" control rooms (refineries, cement works, iron and steel works). These studies focused primarily on operation under normal conditions. In its initial (internal) reports established in 1983, IPSN summarized the key results of these studies in order to raise awareness amongengineers in charge of conducting safety assessments or expertise on human-machine interactions at NPPs.

These studies revealed **the central role played by anticipation in control room monitoring**. For example, in the continuous-process industries studied, it was found that operators do not wait for an alarm or fault to appear in the control room. Instead, they seek to anticipate the physical and chemical changes of processes in order to act before problems occur. These operator interventions help to smooth out changes in the process, which is beneficial for production quality. They also make it possible to anticipate some transients that, although not risky in themselves, may put the operating crew in a difficult position or even put challenges of varying intensity on the facility.

These studies also showed that **monitoring is an activity that is focused as well as all-encompassing**. It is focused because operators have to concentrate all their attention on the actions that they are doing to avoid making mistakes. They have to direct their attention on certain parts of the facilities to be able to clearly assess various phenomena. At the same time, however, they have to maintain a bird's eye view so as not to overlook malfunctions or in order to be able to notice overall changes in the process.

They also showed that monitoring is an activity that is training and experience-oriented. It is widely acknowledged that operators will prefer to monitor parameters related to functions important to production quality and operating safety. However, the study results enabled to qualify this statement. Indeed, operators integrate their operating experience and tend to prefer to monitor systems that are proned to malfunction or have adjustment issues. Equally, they tend to interpret changes in observed parameters first by referring to changes to parameters of the same type that they have previously encountered.

C) Four-party study program involving CEA, EDF , Framatome, and Westinghouse Operator action

Initially, the goal of this four-party program was to study the response time of operators during accident simulations in order to provide data for the probabilistic safety assessments (PSA). However, in 1981, EDF decided to supplement this quantitative approach with a qualitative analysis of the difficulties encountered by operators during simulation tests. Various baseline accident scenarios for PWRs (large RCS break, steam line break inside the containment, steam generator tube break, etc.) were thus "acted out" by operating crews on the simulator at the Bugey training center in April and May 1982.

IPSN conducted its own qualitative analysis of the data collected during these simulation tests. This analysis revealed that the recovery phase of accident is the most problematic for operating crews. The simultaneous management of several concurrent or conflicting objectives was identified as a source of difficulty. The crews that best succeed in overcoming these difficulties are those who have a good ability to anticipate changes in physical phenomena. In particular, it enables them to not focus on instantaneous changes in parameters. Crews who lack this ability tend to gather information from multiple sources and perform multiple checks, leading them to work "in fits and starts" and have a fragmented view of the facility. Team cohesion and proper coordination of the activities of each member also appear to be factors that can promote the development of foresight capacity.

Furthermore, at the end of the analysis of the simulation tests, EDF and IPSN considered that more specific behavioral data needed to be collected in order to better identify operator strategies and reasonings. Although collecting oral data during the interviews conducted at the end of the tests was envisaged, IPSN considered that it was important to couple the statement with objective data. This led to a feasibility study on the use of electrooculography[237] as a means of studying visual-exploration strategies during work in the control room.

11.2.2. The N4 series: the first computerized control room

A) New interfaces and new questions

Following the TMI accident, EDF decided to install a computerized control room in its future 1450 MWe reactor (N4 series). EDF wanted to benefit from advancements in computing that made it possible to filter and rank information and structure its presentation in control rooms. For example, there were now alarm processing and ranking systems, automatic operating sequences, and screens for displaying views of facilities by system, by function or by other logics.

EDF also decided to modify the design of the emergency operating procedures of its reactors by adopting the state-oriented approach (SOA)[238]. The purpose of SOA is to

237. A technique for following eye movements.
238. See "Elements of Nuclear Safety", J. Libmann, chapter 14–IPSN/Les éditions de la physique – 1996.

characterize the operational state of the reactor[239] and gradually bring it back within a safe operating range regardless of the events that caused the degraded conditions. An SOA procedure is a flow chart consisting primarily of questions that the operator must answer by "yes" or "no" and which provides the operations to be carried out depending on the answer. In the case of the N4 series reactors, these procedures are computerized. Using a trackball and the arrow keys of his/her keyboard, the operator follows the "steps" in the image of the flow chart. Information that the operator needs to follow the procedure (parameter values, excerpts of circuit diagrams, etc.) is displayed on the image. The key operating parameters are displayed in a "dashboard" on a second screen. On a third screen, the operator can display more detailed views of circuits, systems, and parameters (e.g. pressure/temperature diagram) and make the necessary adjustments. A number of steps in the flow chart are controlled by the computerized procedure. The procedure compares the operator's answers with those calculated by the computerized control system using data provided by sensors. If a deviation is detected, the relationship with the previous step in the flow chart is displayed in red. These are retroactive checks that the operator can either accept or refuse to take into account. This is referred to as "overriding the step." In addition, most of the procedures are monitored by the computer system, which periodically checks whether the answers given by the operator as he/she proceeds through the procedure are in line with the changes in the parameters. The system alerts the operator when an answer is no longer valid so that he/she can directly go to the relevant step.

The impact of these new operating arrangements on the activity of plant operators raised new questions. To validate its design choices, EDF equipped itself with a full-scale simulator comprising a mock-up of the future control room coupled with a "process" simulator to allow the crews to "experiment" with operation under various scenarios. Dozens of tests were conducted during campaigns held between 1987 and 1996. These consecutive campaigns made it possible to assess the control room's suitability to the requirements of the operating crew's activities. Operation under normal conditions was assessed during the first two test campaigns. Emergency operation was tested between 1994 and 1995, with the development of the computerized operating procedures.

Although the knowledge acquired by IPSN during the aforementioned research enabled to expertise the NPP operation under normal conditions, the computerization of the emergency operating procedures raised new questions, prompting IPSN to conduct new research.

B) Study on operator guidance during emergency operating procedures

In 1994–1995, EDF conducted a series of tests with a simulator to validate the use of the computerized procedures. The purpose of these tests was to ensure that the means provided to operators effectively enabled them to operate a nuclear facility in acceptable safety conditions, in particular during emergency situations. They consisted in closely observing how operators did their job, i.e. the suitability of their operations in the control room. At the end of the tests, IPSN considered that, in order to better understand how

239. The term "process" is also commonly used.

the operators performed, it was necessary to study their cognitive activities (perceptions, interpretations, reasoning, etc.):

- On what basis does an operator identify deviations?
- How do operators construct their vision of changes in reactor operation state?
- How do they understand how the procedure constructs its "own vision" of these changes?
- How do operators call on the rest of the crew to confirm their opinions?

Working with researchers at CNRS, IPSN analyzed data that it had collected during several tests that it had followed. These data consisted of:

- the facility parameters recorded by the simulator;
- audio recordings of the tests (alarms, information provided orally or by telephone, orders, keylogging (to follow operators as they proceeded through each step in the computerized procedures), private discussions in order to identify areas of confusion or hesitations, etc.);
- video recordings;
- comments provided by two control room experts: one with extensive experience in non-computerized control rooms and emergency operation using simulation technology, the other with solid technical expertise in computerized procedures.

This research made it possible to better understand the impact of step-by-step guidance of operators by the procedures [11]. Considering the possibility that operators could carry out unacceptable actions, it can appear appropriate to develop a form of guidance that would tell operators what actions to take. The computerized SOA procedures appear to have been engineered with this view. Indeed, they were designed to break down facility operation to a maximum, both in terms of diagnostics and the operations themselves. The horizon of each action is greatly circumscribed by the steps in the procedure, forcing operators to adopt a step-by-step approach to control.

Close analysis of the activities performed by operators to respond to the steps in the procedures revealed that they use a multitude of skills that are not made explicit by the procedures. The use of these skills assumes that the operators are trained. However, there are so many skills that it is unrealistic to imagine that operators will ever know everything. In addition, some skills are specifically tied to emergency situations and thus will only be used very rarely. To overcome these difficulties, the form of guidance must help operators to enlist their skills when following procedures.

The study showed that the visualization of the overall structure of procedures helps operators to understand the logic behind the current operation and helps them to enlist the necessary skills. Indeed, interpreting the previous steps in a procedure is almost always necessary to interpret a subsequent step. Equally, the relevance of the step's interpretation will be reinforced if operators can see the consequences of their choices. Conversely, strictly following each step in a procedure promotes operator lock-in that appears to lead to a type of withdrawal and passivity, making it sometimes difficult for operators to take initiative when necessary. Operators who passively follow procedures are not able to effectively enlist their skills. These observations concur with the results of two studies conducted in other sectors of industry. A 1987 study [12] on the interaction with an expert system for diagnostic in maintenance activities showed that this interaction resulted in inadequate results if operators passively follow the system's recommendations without constructing in parallel its own diagnostic. Likewise, a 1996 book [13] cites an experimental study on the interaction with a flight planning system. The study shows that *"the pilots allowed themselves to be influenced by the system and lost a certain level of critical thinking. They accepted illogical choices that they never would have considered without the system."* In order for guidance to be efficient, we must get better at taking into account the need for active involvement of the operator in control operations. Guidance thus must allow operators to take a certain distance from recommendations given in procedures.

This research also makes it possible to better understand **operators' positions with regard to guidance that they find unsuitable**.

These differences between the operator's viewpoint of the procedure's "viewpoint" occur in various situations. For instance, an operator may take changes trend in the reactor's state into account, whereas the step in the procedure reflects the reactor's instantaneous state. The operator may find it hard to follow actions that are recommended by the procedure but appear not to be optimized. The operator may find it hard to follow the recommended order of multiple actions whereas one of these actions is perceived as urgent. These differences in viewpoint reveal the operator's active position in relation to the recommendations in the procedure. They show his/her ability to resist the lock-in effects caused by the step-by-step guidance of the procedures discussed above. They can be beneficial to operators, as they provide opportunities for operators to check the validity of their interpretation of changes in reactor state.

Two outcomes are possible when an operator notices a difference between his/her point of view on changes in the process and that of the procedure: the operator either overcomes this difference and continues to follow the procedure or he/she stops following the guidance and risks becoming completely disoriented.

An operator moves past a difference when he/she factors in additional information allowing him/her to understand the reason for the difference. In this case, this difference becomes understandable and the operator can accept it—at least for a certain time. Take the example of an operator who wants to carry out an action not prompted by the procedure. This difference in viewpoint can be overcome if the operator sees that the action in question is dealt with by the procedure a few steps later in the flow chart. The operator can also overcome this difference, without understanding the logic behind it, provided he/she deems that it is acceptable to continue following the procedure. This acceptability will, in part, depend on the conflict that may appear between the recommended action and the operator's knowledge. But the fact that the procedure causes the operator to act against his/her knowledge—to put it aside—can lead to a loss of credibility in the procedure or encourage the operator to adopt a passive attitude toward the procedure and result in the negative effects presented above.

11.2.3. The EPR project: the move toward increased automation

A) Design principles

As for the N4 series, EDF decided to fit the EPR control room with a digital instrumentation and control system driven by a computerized man-machine interface. A goal of the project from the very outset was to increase the level of automation in particular to help to reduce the number of actions to be performed by the operating crew, lighten their workload, and establish lines of defense regarding inappropriate actions which could be taken by the crew.

This automation applied to the start-up and shutdown of equipment (e.g. automatic connection of the residual heat removal system [RHRS] during normal operation), the introduction of new regulations (e.g. for the auxiliary feedwater supply of the steam generators in shutdown states, the supply of borated water) and of new operator support functions intended to introduce automatic corrective actions to avoid activating the reactor protection system. In addition, an automatic reactor state diagnostics system was introduced to aid in emergency operation. Using the main parameters for the reactor state and the primary and secondary systems, this facility-monitoring system suggests the operating strategy to be implemented by the operating crew during accidental situations.

In light of these trends, IPSN began conducting a literature review in 1995 in order to make a status of research on human-automation interaction. This work made it possible to characterize two approaches to automation. In what is referred to as the technician-centric approach, automation is a solution of choice for reducing operator intervention and thus reduces the risks of human error. Operators thus carry out a set of residual functions that are often imprecise in definition and can be detrimental to the overall effectiveness of the human-machine system. An alternative approach consists in viewing automation as a tool for enhancing operator performance. This means that automated systems must therefore be designed to be compatible with the characteristics of human activity (perception, reasoning, cooperation, interaction, etc.). This activity-centric approach calls into question systematic automation based on the analysis of its negative impacts on this activity.

This literature review also made it possible to identify areas to be examined more closely—the impact of automation on the control of the operation of a process by operating crews, the ability to acquire knowledge through operating experience, modes of cooperation between operating-crew members, the level of trust in automation, the degree of independence, and operator involvement in reactor operation.

B) Study of the impact of automation on operator performance

Between 1996 and 1998, IPSN led a research project and the Halden Man-Machine Laboratory (HAMMLAB) in Norway—which is affiliated with the Halden Reactor Project (see "Focus" below) — to study the impact of automation on operator performance (Figure 11.1). This research was conducted on the laboratory's NOkia Research Simulator (NORS) (PWR version of the VVER 440).

Figure 11.1 The facility at HAMMLAB during IPSN's experimental work. © DR.

The purpose of the research project was to understand how operators integrate the effects of automated actions when they manage a situation and must anticipate its progression. An experiment taking account the type of automation (extended vs. limited) and type of operations activity (diagnostic or operating sequence) was conducted at HAMMLAB to answer this question. Diagnostics situations were characterized by their gradual deterioration, with operators having a certain latitude and having to foresee future changes. The operating sequences had to be performed either manually or automatically in order to achieve a change of state. Six scenarios lasting around one hour were acted out by six operating crews.

Several independent variables were measured during the tests for quantitative analysis purposes. These included:

- measuring the overall performance (crew & automated systems) based on the achievement of some specific reactor parameter values;
- measuring operator performance during time windows predefined for each scenario and which ranged from the occurrence of a failure signal to the completion of a response action by the operating crew;
- measuring situation awareness through the operators' responses to a questionnaire about the values of certain parameters. The questionnaire was given several times during a test while the simulator was in pause mode;
- measuring trust in the automated systems *via* a questionnaire at the end of each test.

This analysis yielded a number of findings, such as:

- during diagnostics situations, operators tend to place more trust in automated systems when they have a limited scope of action;

– during operating sequence situations, extensive automation increases overall performance and reduces operator workload;
– human intervention remains preferable in complex diagnostic situations, for in this case extensive automation does not lead to good overall performance.

#FOCUS

The Halden Reactor Project

The Halden Reactor Project was created in 1958 under the joint leadership of the OECD and the NEA (www.oecd-nea.org/jointproj/halden.html). It is being carried out at the Institute for Energy Technology (IFE), in Norway, and is supported by 19 countries, each which funds research in areas such as nuclear fuel, the behavior of materials in nuclear environments, organizational and human factors, human-machine interfaces, etc. Some of this work is conducted by making direct use of a small 20 MW experimental reactor (the Halden reactor is a boiling heavy water reactor—see Figure 11.2) that regularly contains more than 30 experimental devices at the same time. Research on organizational and human factors is based on simulations conducted within the Halden Man-Machine Laboratory (HAMMLAB).

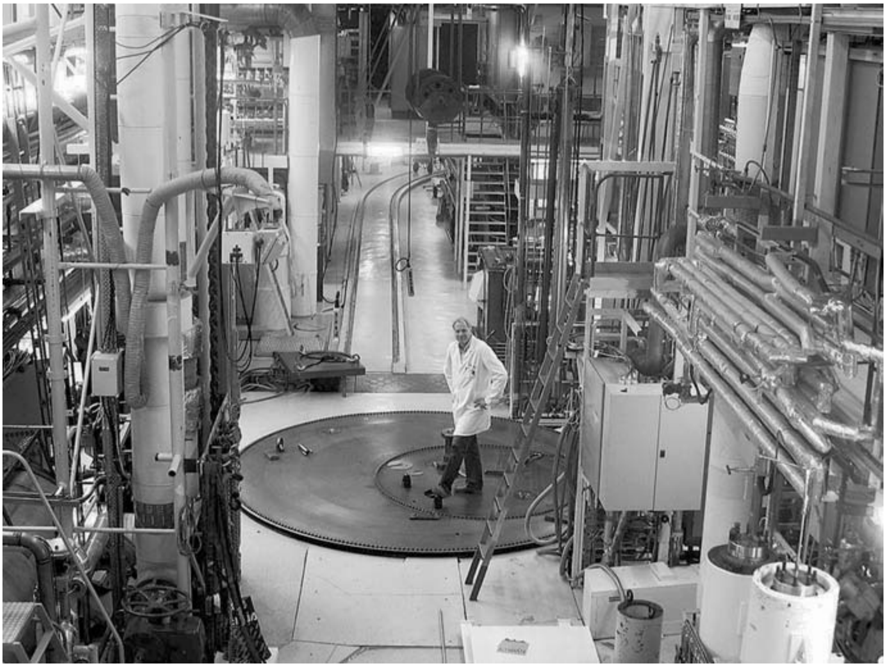

Figure 11.2 View of the Halden reactor hall. © IFE (Institutt for energiteknikk).

11.2.4. Contributions and outlook

The knowledge acquired through this research constituted as many "points of attention" for IPSN's expertises. It was therefore considered that EDF's decision to create a "safety and radiation protection engineer" position would make it possible to limit the focus effects, and even lock-in effects, created by unexpected situations and the importance of which has been highlighted by the studies. In another example, IPSN considered that including coordination points in the accident procedures should offset the risk of the operating crew being split up during unexpected high-stakes situations. Likewise, the results of the study on use of computerized procedures were used by IRSN in its assessment of the EPR control room, in particular to emphasize the importance of providing operators with an overview of the current procedure in order to allow them to understand the operating strategy.

Given the constantly evolving technologies that provide operating crews with new functionalities, this research on the operational activities of reactors shall be continued. One example is the development of embedded systems that will allow field workers to locally obtain multiple data on the status of systems and provide control room operators with much more accurate information about real field conditions.

They must also be continued to derive lessons from the Fukushima Daiichi accident. IRSN thus conducted an in-depth investigation of all of the official reports and accounts that were published about the Fukushima accident. It published its findings in a report titled "A Human and Organizational Factors Perspective on the Fukushima Nuclear Accident" [14]. This report highlights a number of consequences of the total loss of power to the control room: *"At 3:37 p.m., the control room [of reactors 1 and 2] lost all electrical power and was suddenly plunged into silence and darkness, leaving the operators to use flashlights to read the emergency procedures. These procedures were of no assistance in managing the nuclear reactor, however, as the indicators used to monitor its operation were out of action. It became impossible to check the parameters essential in cooling the reactor: the water level and the vessel and containment pressures."* This study has also made it possible to identify issues that deserve closer examination. For example, what knowledge should be used to collect and interpret information on the state of the systems when indicators and procedures are no longer operational following total loss of power to the control room? How can real cooperation be maintained between the control room and emergency-response center once means of communication are no longer operational?

11.3. Studies and research on the organization and management of safety at EDF's NPPs

It was not until the early 1990s that IPSN conducted its first study on the organization and operation of reactors (human factors and organization of unit outages[240], see

240. Term used to designate reactor shutdowns during which the reactor is reloaded with fuel assemblies, maintenance is carried out, and other operations are performed.

Section 11.3.1 below). Previous studies had only focused on operating crews and control room design. Although these organizational studies were prompted by the emergence of issues on the safety of maintenance operations, they also benefited from research conducted by U.S. sociologists on organizational reliability in the wake of the TMI accident.

In 1984, a book with the provocative title of "Normal Accidents: Living with High-Risk Technologies" [15] was published. Providing an in-depth analysis of several industrial accidents, including TMI, it uses the term "normal accident" to emphasize accidents that are related to the very nature of high-risk systems. Adding protections to the systems in fact increases their complexity, which increases their possibility of failure, reduces the ability of operators to understand their overall operation, and in turn increases their vulnerability. Furthermore, the components of these complex organizations are tightly coupled, meaning that what affects one component may affect its related components as well.

Following the publication of *Normal Accidents, living with high risk technology,* some researchers considered that the viewpoint presented in it was not borne out by actual accidents affecting high-risk systems, which were extremely rare. They thus sought to understand how high-risk industries were able to maintain a high level of reliability. The movement known as High Reliability Organizations (HRO) was created by a group of researchers at the University of California, Berkeley[241]. Their work explains the organizational measures and methods implemented daily by HROs to maintain a high degree of reliability. It emphasizes the positive role of organizational flexibility, i.e. rallying several levels of operation in the organization depending on the situation, the redundancy of checks by people, strong consistency between the organization's goals and individual goals, recognition of the importance of the skills of people whatever their level in the hierarchy, and the continuous organization of training and refresher training courses, the co-existence of centralized decision-making and decentralized operational decision-making.

This research remained relatively unknown in France in the 1980s. It was not until a 1999 thesis titled *Le nucléaire à l'épreuve de l'organisation* [16], that information about the HRO paradigm spread. This thesis also emphasized the paradigm's limits and proposed new developments.

Another work of interest is Diane Vaughan's "The Challenger Launch Decision—Risky Technology, Culture, & Deviance at NASA" [17]. Published in 1996, it explores the reasons behind the Challenger accident and analyzes several aspects of the organization at various time spans. It thus looks at the interactions between engineers in the hours preceding the launch of the shuttle as well as the relationship dynamics between NASA and the U.S. Government over several years. By focusing on the micro-decisions made at the time, Vaughan shows that what in hindsight appears to be a series of clearly identifiable errors is actually a series of decisions and interpretations that are perfectly understandable in the context in which they were made, but which are in fact slight

241. Todd LaPorte, Karlene Roberts, and Gene Rochlin, joined by Paul Schulman and Karl Weick in particular.

deviations from normal limits and lead imperceptibly to "normalization of deviance". This is one of the key contributions of this book.

Also worth mentioning is the PhD thesis "When designers anticipate the organization to control risk: two installation modification projects on two SEVESO 2 classified sites" completed in 2008 [18]. This thesis, which contains many sociological lessons that cannot all be listed herein, brought to light or confirmed a few of the "workings" that form the basis of organizational reliability:

- the involvement, right from the design of facility retrofits, of operators (in all the relevant fields) and contractors (such as maintenance subcontractors) who will all ultimately participate in the operation of the retrofitted facilities, is a factor of success;
- corrections or additions to the initial design of the facilities is a factor of risks in complex systems (as is a nuclear reactor and its operation).

All of this work will influence the research carried out by IPSN (then IRSN) detailed hereafter.

11.3.1. Organization of maintenance activities

In the summer of 1989, three incidents occurred while maintenance was being conducted on reactors in France's NPPs. These incidents highlighted the fact that safety could be compromised by a forgotten or incorrectly basic operation (gaseous releases beyond the threshold, a latent failure that could have caused an engineered safeguards system to fail during an accident sequence). EDF reinforced its organization starting in 1990. It created new positions (checkers and contract managers), reinforced site engineering and preparation, provided contractors with training on quality and safety, and introduced the performance of a risk analysis prior to all maintenance activities. Although these arrangements may, in principle, reinforce the reliability of maintenance activities, IPSN and EDF agree that a deeper understanding of the conditions of unit outages was necessary to be able to better assess the relevance of these measures.

A) "Human factors and the organization of unit outages: safety challenges"

In 1991, IPSN undertook a study to understand the maintenance work in order to be able to assess the organizational changes proposed by the nuclear reactors operator. An ergonomic analysis of the activities of various workers during two unit outages—in July 1992 and July 1993—on the same site was implemented. In concrete terms, more than 20 projects (essentially related to mechanical work) and the activities of more than 50 workers with various positions were closely tracked. Two requalification tests, among the most complex, of the safety-injection system items were observed. An ergonomist took part in the daily outage meetings during which progress on the maintenance work was checked and rescheduled where necessary. This ergonomic analysis revealed the specific aspects of each worker's job, its specific constraints, and the associated risks, and described how the workers coped with contingencies in their established organization.

Both of these aspects made it possible to identify possibilities of organizational failure and failure in individual work, as well as the implicit strategies and skills developed by workers to mitigate these risks of failure.

The study revealed that **the conditions under which maintenance was performed were insufficiently taken into account** during the maintenance-preparation activities and when drawing up operating experience feedback on unit outages. The little interaction between contractors and preparers was identified as a contributing factor to this situation. Information about the difficulties in carrying out maintenance work did not rise, despite the fact that these difficulties led to unexpected events, lost time, and workers making decisions themselves. All this had a human "cost" and could compromise safety.

The management of unexpected events is a primary concern in the life of workers. Nothing happens exactly as planned and unforeseen events can crop up. When they occur, they must be detected and maintenance work must be adjusted accordingly. Their impact on the safety of this readjusted maintenance work must be assessed in real time. The time and resources needed to do this are often underestimated.

The study also revealed that jobs and skills of diverse nature are involved in the maintenance activities performed during a unit outage. The **comparison of viewpoints** in real time, when organized, helps to ensure maintenance activities are carried out smoothly. With this in mind, skills management and time constraints, attention to collaboration among various maintenance workers, and the creation of structures where limits encountered during maintenance can be openly discussed are elements important to safety.

B) "The organization of unit outages in a period of reform"

In 1994, a study by the Center for the Sociology of Organizations (CSO) was carried out in French NPPs as part of a PhD thesis being written on the organization of work in high-risk systems. Titled "The organization of unit outages in a period of reform," the thesis subsequently found an echo in the 1999 thesis [16] referred to herein. It provided a comparative analysis of the preparation and completion of four unit outages at two NPPs in the United States and two NPPs in France.

The main objective of the thesis was to assess changes initiated by EDF, starting in 1991, to reinforce the organization of its maintenance activities during unit outages. It sought to identify the difficulties encountered during outages. However, it exceeded and renewed the scope of analysis of the previous study (see Section A). On the one hand, it attempted to understand how a number of outage constraints occur during the lead-up to the outage itself. On the other, it sought to understand how some characteristics of the intervention situations are related to overall constraints that burden nuclear sites. In terms of the methodology, the thesis made use of strategic analysis, developed in the sociology of organizations (see, for example, the work referred to herein [19]). It used data collected from 68 interviews to trace back to the "games" that take place between the members of an organization and the strategies that they use to perform their activities and achieve their goals.

The thesis revealed that **setting up a project organization** ("permanent structure of a unit outage") dedicated to the completion of unit outages facilitates the preparation of maintenance operations. However, if the project team is formed around six months before an outage, each department gradually assigns its representatives and some people, such as inspectors, are assigned late in the process. Furthermore, the people assigned to the project team are chosen by their respective departments. Outage project managers therefore do not choose their "troops." The thesis also showed that the "ramping up" of the outage structure was accompanied by a withdrawal of the departments in the preparation of outages. Broadly speaking, the departments did not appear concerned with outage projects, considering that they were solely a matter for outage workers.

Another prominent change observed on the site was **how work is awarded to contractors**. Buyers participate in drawing up work orders and business aspects (the definition of technical requirements, competitive tendering, etc.) play a larger role. The level of detail required in specifications is a source of difficulty for EDF staff, especially for those who lack experience or deal with operations for which it is difficult to anticipate the working conditions. Furthermore, although competitive tendering can help contain maintenance costs, it creates contractor instability and the possibility of having to work with new contractors whose technical expertise remains to be seen over time.

The study also revealed the complexity in the **scheduling of outage work**. A first draft of the master outage schedule is established based on aspects such as the preventive maintenance programs, the retrofits to be made, and constraints related to the provision of tools. The coordinators then define the work packages and send the corresponding orders to contractors. This preparation essentially takes place for each individual package with relatively little overall coordination. The result is that cross-disciplinary activities, such as the procurement of spare parts or routine radiation protection equipment, are insufficiently taken into account.

C) Study on the implementation of EDF's outage control centers

Since 2012, EDF has been implementing COPAT (*Centres opérationnels de pilotage des arrêts de tranche*), its own version of the outage control centers (OCC) in use in North America. IRSN conducted a benchmark study in June 2011 to assess the impact of this new organization of safety and radiation protection. It did so by consulting licensees in the United States and Canada as well as the Canadian Nuclear Safety Commission (CNSC). Prior to this, EDF had conducted its own study in 2007.

EDF's COPATs are designed to coordinate outage activities 24 hours a day to ensure that planned outage schedules are better adhered to. Sensitive phases and sequences of critical activities, which are identified beforehand, are closely monitored. The COPAT is alerted of probable or confirmed deviations of 30 minutes in the critical path in order to take the appropriate arrangements without affecting outages. This assistance makes it possible to solve difficulties encountered during outages more quickly and share real-time information among teams. This organization requires having quick response teams. Its aim is to be able to anticipate potential difficulties and imagine scenarios for managing them by foreseeing the sufficient necessary resources.

IRSN's study made it possible to capitalize the facts, observations, and lessons, particularly regarding the key factors of success, the limits, and the challenges of managing unit outages via outage control centers. Its objective was more to identify key issues than collect organizational solutions. It thus helped to establish a method for assessing EDF's proposal for implementing COPATs. Although the study validated a number of topics for in-depth study that had been identified previously by IRSN (complexity of the management of interfaces between hundreds of people and within projects comprising thousands of activities, forecasting of human resources in a period of massive retirement, integration of hundreds of contractors, operating experience feed-back, change management, etc.), it revealed other important topics to be investigated in detail during IRSN's assessment of the measures adopted by EDF.

The interviews conducted during the study revealed that OCCs were seen as structures that were added to solve problems of coordination and cooperation between operating crews and maintenance crews and bridge cultural gaps. It was thus deemed wise to investigate how COPATs could increase the complexity of unit outage management.

The study also showed the variety of project structures in North America that adhere to OCC principles, have different staffing levels (10 to 20 people), and place various levels of importance of operation and maintenance. The question was thus raised about whether COPATs should be tailored to each French NPP.

It was noted that North American facilities placed importance on preparation (longer by a few months and standardized) and controlling the forecast volume of maintenance. Licensees in North America tolerate only 10% additional unexpected[242] maintenance over the initial volume determined six months prior to the start of an outage. In the case of France's NPPs, this additional maintenance can rise to 100% (50% during the six months prior the outage and 50 % during the outage). This observation raised a number of questions:

- Was there a lack of foresight detrimental to the organization of the preparation of maintenance activities in France's NPPs?
- Was the restriction of unexpected maintenance by North American licensees conducive to organizational success but detrimental to equipement reliability and safety?

The study found that OCC staff had a great amount of expertise (three years as an assistant in an OCC, then eight years in that position) that enabled them to calmly deal with situations, particularly with unexpected events. The situation in Canada and France was vastly different. It was found that COPATs could not be training centers, which related to issues of human resource management.

242. The term unexpected maintenance work encompasses both that which may be overlooked during the inventory made six months before the outage and that which is caused by anomalies found during the six months before or during the outage.

The study also showed that there was a relationship between foresight and responsiveness at licensees in North America. There was a high priority on foreseeing potential failures and scheduling slippages and on being prepared to manage potential unexpected events (capitalization of past unexpected events managed, prepared crews to face similar events). This aspect had to be looked at in the case of EDF's COPATs.

Lastly, the study revealed that North American licensees (30%) significantly outsourced fewer maintenance activities than EDF (80%), pooling of resources among sites, and greater internalization of logistical means (ensuring that maintenance activities are carried out under the right conditions).

11.3.2. Contractor management

The studies conducted between 1992 and 1994 (Sections 11.3.1 A and B) chiefly focused on the organization and performance of maintenance activities during unit outages. In the early 2000s, IPSN decided to conduct research on the use of contractors. There were two reasons for this: contractors are increasingly being used, in particular for maintenance activities, and outsourcing in the nuclear industry is a subject of intense debate that, in the end, has little basis on extensive studies.

A) Outsourcing relationships and their consequences on security and safety

Some research emphasizes the difficult working conditions of some employees of contractors and directly link these difficulties to their subcontractor status. The use of contractors is thus seen as a factor that deteriorates working conditions and even the very quality of work and thus safety. However, some arguments cast doubt on this negative effect of outsourcing. For example, some types of sensitive equipment (pumps, valves, etc.) have always been maintained by the employees of their manufacturers ever since the first NPPs were commissioned. This situation is widely viewed as an assurance of quality. Likewise, some maintenance tasks are extremely difficult regardless of which employee is performing them. In order to more clearly identify the effects of outsourcing, the research focused on the outsourcing relationship, how this relationship is built through the joint action of the project owner and the contractor, and how this relationship affects not just the work of contractors' employees, but that of the project owner's employees as well.

Such research was conducted as part of a sociology PhD thesis in collaboration with the French rail operator SNCF and the French Gas, Network management, Distribution Company GrDF [20]. This partnership made it possible to access maintenance projects to replace railroad tracks and track ballast (SNCF) and to replace gas-distribution networks (GrDF). These projects were carried out mainly by the employees of contractors. More than 50 interviews were conducted with the local, regional, and national employees of SNCF and GrDF. These employees were in charge of preparing and conducting the maintenance projects and providing feedback on them. These interviews made it possible to collect data on the meaning each employee ascribed to their work practices, how they saw their work, and the ties linking them to the contractors. Several projects were also observed as they took place. For example, a project to replace track ballast and railway ties in Northern France (November 2007 to January 2008) was followed, making it possible to attend initial project planning and scheduling meetings, follow an employee in charge of bringing in and clearing out the work trains on the railtracks, and more.

Although the findings yielded by this research are too numerous to mention here, it provided some important observations and important lessons.

First of all, this research made it possible to provide a typology of the various types of outsourcing activities[243], including in the case of insourcing by a contractor. Aspects of "cascading" outsourcing were also discussed in this research.

The research also revealed that there are many types of relationships between project owners and contractors and that they depend in particular on the extent of outsourcing, how much technical skills are shared between project owners and contractors, their degree of mutual dependence, and the duration of outsourcing agreements. The 2003 collapse of the gangway leading to the Queen Mary 2 liner at the Saint-Nazaire shipyard is cited as an example highlighting a number of aspects of the relationships between the project owner (Les Chantiers de l'Atlantique) and its contractor (SAS Endel) that jeopardized safety at the shipyard and ultimately led to the accident[244].

The thesis showed how much the premise that "*the market' quality, cost, and turnaround time results—always better than those obtained internally—make it easy to overlook the transaction costs required to remain in control of facilities*". Indeed, outsourcing often leads to "virtualization" of safety or security where hands-on monitoring may be severely decreased (or even prohibited) in favor of supervision based on the validation of technical studies and the verification of data used by contractors with reduced hands-on checks ("paper-based" safety or security). "Cascading" outsourcing can compound this situation and cause "*risk to migrate to the weakest links in the outsourcing chain*."

The thesis furthermore emphasized that outsourcing affects the project owner's internal organization, thus challenging the "*idea that outsourcing is simply a "transfer" of operations to the contractor without any deep-rooted changes to the organization in which the change occurs*."

Another aspect highlighted is that "*it is impossible to study the link between outsourcing and safety or security with a rationalistic vision consisting in identifying factors that would directly affect safety or security and lead to the conclusion that managerial intervention on such-and-such factor would, with such-and-such percentage of odds, guarantee safety or security*". The thesis shows the oversimplification of the outsourcing "approach" from the sole perspective of the "sustainability of the skills" of the project owner and "contractor monitoring." Outsourcing must be considered and analyzed as a relationship or partnership.

243. Technology-driven or capacity-driven insourcing, technology-driven or capacity-driven external subcontracting, and outsourcing.
244. These factors were clearly established by the criminal investigation into the accident.

The thesis also pointed out that "established" contractors—thanks to their acquired (and well-earned) reputation—can become elevated to favored status: "*contractors who know that they are well positioned create a lot of leeway for themselves*".

These findings and lessons are points of attention in IRSN's assessments of outsourcing practices used by licensees, in particular those conducted on EDF in 2015. They also opened the way to other tracks of research, such as that carried out as part of RESOH research chair.

B) Outsourcing relationships—the RESOH research chair

Inter-organizational relationships, such as outsourcing, were seen as a source of advances in safety following the progress made in human and organizational factors of safety since the 1980s, a fact attested as much by the conclusions of the complementary safety evaluation (ECS) conducted by IRSN and ASN following the Fukushima accident. The Chair of Safety, Organization, and Human Research (RESOH) is dedicated to studying organizational and human factors of safety at high-risk industrial facilities throughout their life cycle (design to dismantling and waste management). It focuses in particular on these inter-organizational relationships.

RESOH was created in March 2012 by its four founding partners—the École des mines de Nantes, IRSN, AREVA, and DCNS—for a five years duration.

The RESOH research chair focuses on two areas of research:

- inter-organizational relationships, in particular *via* the development of outsourcing and co-contracting relationships[245];
- the integration of safety in all the constraints and management systems related to research on industrial competitiveness.

Safety is a collective "construct" that brings into play the liability and individual activity of not just each contractor, but of teams and institutions as a whole as well (project owners, contractors and co-contractors, inspectors, etc.). RESOH's objective is to analyze the construction of safety at the scale of the system formed by the complex relationships between all of these parties and by taking their environment (economic, legal, social, etc.) into account.

Its aim is to provide answers to these issues by identifying the vulnerabilities, robustness and resilience[246] of these contracting and co-contracting networks and by studying the managerial practices and management systems that can enhance safety within them.

RESOH uses two research methods:

- qualitative field studies that call on techniques used in the sociology of work and organizational ethnography;

245. This term describes the pooling of contractors (consortium) for the purposes of providing service for a licensee.
246. Adaptability to unexpected situations.

– an observatory on outsourcing practices, for quantitative and cross-disciplinary purposes.

RESOH aspires to bring in additional partners and thus explore other areas of industry.

Its research on the management of complex projects and the use of outsourcing covers two aspects:

– the contribution of unit outage schedules to improving time management and coordination between parties;

– the role agreements play in mutual commitments between project owners and contractors.

This research is grounded in field studies conducted with AREVA (La Hague) and DCNS (Cherbourg).

11.4. Research on human and social sciences: the AGORAS project

In his introductory message to official report by the Fukushima Nuclear Accident Independent Investigation Commission commissioned by the National Diet of Japan, Chairman Kiyoshi Kurokawa mentioned a number of societal factors "*that could and should have been foreseen and prevented*". He wrote of "*mindset that supported the negligence behind this disaster*" *(...)* "*made in Japan*" Chairman Kurokawa's reflections have a general scope and should be of concern to any party involved in the "governance" of risks of any type. It was in this field of human and social sciences that IRSN decided, in 2012, to conduct new research, in particular as part of the AGORAS[247] project. Rather than investigate the human and organizational factors that contribute to the operational safety of nuclear facilities, it focused on the general functioning of all stakeholders involved in ensuring safety.

In France, the complementary safety evaluation (ECS) conducted in wake of the Fukushima accident pointed up the importance of studying the link between safety and inter-organizational relationships. It was this as yet little-explored topic that became the focus of the AGORAS project to improve governance of nuclear safety organizations and networks. AGORAS was selected in late 2013 as part of a call for nuclear safety and radiation protection projects launched by the French National Research Agency (ANR) and spurred by the highest levels of France's Government. Its goal is to understand how institutional equilibriums among licensees, subcontractors, partners, and also safety regulators and public assessment bodies are built and evolve in a world where civil society is playing an increasingly greater role. Emphasis will be placed on the dialog that is established between stakeholders and which partially forms the basis of safety in the nuclear industry as a whole.

247. *Amélioration de la gouvernance des organisations et des réseaux d'acteurs pour la sûreté nucléaire*.

Expected to last six years, AGORAS is structured around two aspects—accident prevention and emergency management. The goal of the first aspect is to analyze the impact of the Fukushima accident on the safety "approach" for nuclear facilities and the relationships among those involved in the governance of nuclear risks. The goal of the second aspect is to analyze how this accident has helped to change the perception of nuclear accidents and the methods used to manage the preparation of accident and post-accident situations. It will look at changes in emergency-response organizations and doctrines since the TMI accident by analyzing feedback obtained for emergency exercises and actual emergencies (the flooding of the Blayais NPP in late 1999 is a possible example). The expected results should reveal vulnerability factors related to the growing complexity among emergency-response teams and institutions, tracks for improvement and opportunities making simulation exercises more realistic.

IRSN is coordinating two efforts as part of the project. The first (2014–2018) will identify organizational and cultural conditions that influenced decisions about the Fukushima NPP (technical choices, design options, etc.) and which ultimately proved to be inappropriate. This effort comprises two areas of research:

- the first, the study of assessment processes and technical decisions, consists in understanding, as part of a socio-historical analysis developed to analyze a number of major accidents (such as the Challenger Shuttle disaster), the dynamics and factors that may explain certain concepts, tools, and data that are poorly known, ignored, or inadequately taken into account by all stakeholders involved in the governance of nuclear risks. It is based on an analysis of French cases;
- the second consists in analyzing the preparation and implementation of risk-control documents, such as the "extreme cold weather baseline" or the "flood guide" (see Section 8.2 herein). The aim is to analyze the dynamics and representations at work during their preparation and how they are able to either strengthen or weaken the legitimacy of the documents. How are some proposed tools, data, recommendations, or approaches interpreted and used? Which deviations or amendments in relation to the initial intentions of the designers of these documents are ultimately accepted by regulators? What are the limits, checks and impact assessments?

The second action (2013–2018) relates to technical dialog during the post-accident complementary safety evaluation (ECS) to understand how the occurrence of a major accident can lead to a reassessment of previous safety practices. This involves identifying the conditions that both favor and impede reassessment. Complementary safety evaluation (ECS) has effectively opened a period of intense technical dialog among licensees, ASN and IRSN. In concrete terms, the goal will be to answer the following questions: What new inter-organizational dynamics will be brought to light by the lines of reasoning and potential controversies among the stakeholders? Which "paradigm breaks" (the unforeseen accident has happened) or, on the contrary, what lines of "defense" will underpin these lines of reasoning? How will media coverage of some debates and the particularity of extending the service life of NPPs affect the positions and arguments of key players of nuclear safety?

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