Nuclear Safety
NEA/CSNI/R(2015)16
October 2015
www.oecd-nea.org

Human Performance under Extreme Conditions with Respect to a Resilient Organisation

International Workshop
Proceedings

24–26 February 2015
Brugg, Switzerland

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Unclassified **NEA/CSNI/R(2015)16**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **20-Oct-2015**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2015)16
Unclassified

Human Performance under Extreme Conditions with Respect to a Resilient Organisation

Proceedings of a CSNI International Workshop

24-26 February 2015
Brugg, Switzerland

JT03384549

English text only

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was created in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety among NEA member countries. The main tasks of the CSNI are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The priority of the CSNI is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs, the committee provides a forum for improving safety-related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA Committee on Nuclear Regulatory Activities (CNRA), which is responsible for issues concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with other NEA Standing Technical Committees, as well as with key international organisations such as the International Atomic Energy Agency (IAEA), on matters of common interest.

EXECUTIVE SUMMARY

After the Fukushima Daiichi accident a number of initiatives have been undertaken internationally to learn from the accident and to implement lessons learned to improve nuclear safety. The accident has shown in particular the challenges in supporting reliable human performance under extreme conditions. Acknowledging that further work is needed to be better prepared for the HOF (Human and Organisational Factors) challenges of the extreme conditions that may be present in severe accidents, the NEA's Working Group on Human and Organisational Factors (WGHOF), one of the working groups for the Committee on the Safety of Nuclear Installations (CSNI) initiated a new task with the objectives to:

- share experiences and knowledge of human and organisational performance under extreme conditions,
- identify specific currently applied HOF principles in nuclear and other high risk industries and compare them with the available knowledge,
- provide a basis for improvements and necessary research taking into account HOF issues in the design and use of measures, and
- make recommendations with the aim to achieve the best level of human and organisational performance as possible under extreme conditions.

In order to move those issues forward WGHOF hosted together with the Swiss Federal Nuclear Safety Inspectorate ENSI a workshop entitled "Human Performance under Extreme Conditions with respect to a Resilient Organization". The workshop took place in Brugg, Switzerland in February 2014. The workshop was conducted with participation of a number of invited key speakers from academic research and a range of industries, including nuclear. Thirty-four experts from 12 countries, the IAEA and OECD/Halden participated. Experts came from nuclear authorities, research centres, technical support organisations, training simulator centres, utilities and from non-nuclear field (aircraft accident investigation, firefighting, military, design of resilient organisations).

From the discussions at the workshop, it is clear that the accident at Fukushima has illustrated the challenges that can face operations and emergency response staff in dealing with a major nuclear incident. In addition to the complexities of understanding what is happening in the reactor and taking appropriate actions, people were exposed to a harsh environment (e.g. loss of power, radiation, lack of tools, fatigue, etc.) and demanding psychological factors (e.g. shock, disbelief, uncertainty and fear related to personal and family situations, etc.).

Moreover, the Fukushima accident had fundamental implications for our understanding of accident management. The traditional approach to such accidents is to seek improvements in reliability that should prevent recurrence and provide staff with measures (procedures and equipment) that can be applied. The difficulty with this approach is that the increased complexity can lead to unanticipated situations that render the pre-planned responses inapplicable and ineffective. One of the fundamental conclusions from the workshop is that in addition to reliability, the focus should be on increasing resilience through improving flexibility. In addition, the workshop has identified the following good practices and research needs in the areas of human capabilities, organisation and infrastructure.

Human capabilities

In responding to severe accidents, human capabilities pose both advantages and disadvantages. People can be very resilient – when faced with a problem, they can find creative solutions. For example, people use pattern-matching to help make sense of new situations and determine appropriate actions. At the same time, the stress associated with a severe accident can limit human performance. People can become overwhelmed and mentally fatigued leading to poor cognitive behaviour and decision-making.

Good practises:

1. Put in place pre-planned responses for the very early stages of a severe accident – e.g. preparatory activities, mobilization of resources, information gathering. This allows personnel to get over shock, gain some understanding of the situation, and start on a successful note.
2. Use realistic exercises to test and develop response capability. These are particularly important to testing lines of communication, decision-making, improvising and re-planning capabilities, leadership and team behaviour.
3. Recognize that stress will be a reality and ensure that there are mechanisms for addressing stressors such as uncertainty in family situations, and that there are staff rotation plans in place.
4. Establish an observer role – a person responsible for watching team dynamics, fatigue, when, for example, teams are stuck. Such a role is important to helping make changes before stress and fatigue have an adverse impact. Train personnel that will be in leadership roles in the requisite interpersonal and communications skills. This should include sense-making (see below).

Research needs:

- Error modes during extreme events: The existing extensive database on human error during more routine events should be built on to include what might be expected during extreme events. In particular stress research needs to be integrated into cognitive psychology.
- Extent of realism required for exercises: There are ethical considerations in the introduction of stressors and uncertainty in the benefits of pushing scenarios to failure. For example, should situations requiring sacrifice decisions be included.

Organisation

Managing for the unexpected and developing resilience requires organisations to broaden their processes. Two important attributes in this regard are the ability to understand and communicate complex situations to staff (provide a sense-making story), and the ability to recognize when the situation has evolved or the current sense-making story needs adjustments (watch for anomalies).

Ensuring organisational performance for both design-basis events and severe accidents poses a significant challenge. The organisation has to achieve a balance in centralized and decentralized processes for decision making, and a balance in a rigid adherence to procedures and a flexible response to symptoms.

Good practises:

1. Ensure that accident management teams are provided with clear lines of communication and clear authorities for distributed decision making in advance of any incident.
2. Establish an emergency management process that involves regular “stop-points” to review the current situation and determine if the plan of action needs to be revised (watching for anomalies).

3. Identify reserve capacity (people and equipment) that can be used to provide necessary flexibility to respond to the unexpected.

Research needs:

- Transition from rule-based procedures to knowledge-based approaches (compliance to resilience): Normal operations and design-basis accidents rely on rule-based procedures to guide staff actions, whereas severe accidents use a knowledge-based approach. This represents a shift in both decision-making authority and processes that would benefit from research on how to ensure the transition is effective.
- How can organisations be flexible and agile during emergencies while maintaining reliability during normal operation?
- Regulatory oversight practises for resilience: The traditional approach to regulatory oversight is to assess organisational compliance using pre-established criteria and processes. As resilience is based on ensuring flexibility, a different approach to regulatory oversight may be required. Resilience measures: What are leading and lagging indicators of organisational resilience?

Infrastructure

The infrastructure required to respond to severe accidents includes both off-site and on-site capability. This infrastructure should include resources and equipment that is sheltered from potential initiating events (earthquakes, severe weather, etc.), and capability to move equipment to where it is needed. Specific consideration needs to be given to multiple failures that could result from a common cause – e.g. severe weather events impacting multiple units on the same site, or on different sites.

Good practises:

1. Provide redundant infrastructure and equipment (including transportation equipment) necessary for resilient emergency response; and ensure the infrastructure and equipment is adequately sheltered.
2. Pre-establish inventory of systems and components that may have an alternate use during emergencies (e.g. electrical systems, water-supply systems including fire pumps).
3. Ensure consideration is given to events that unfold over an extended time period – how will transitions between response teams be managed? – how will the basic living requirements (e.g. housing, food, clothing) be met?
4. Involve off-site emergency response capability in exercises to ensure lines of communication are effective and overall emergency response will be effective.

Research needs:

- How should updated risk assumptions (event frequency and consequence) drive changes to the emergency response infrastructure?
- Resilient procedure use: Can resilient procedure use, i.e. adapting existing procedures to unanticipated situations, provide an approach to smoothing the transition between a rule-based approach to a knowledge-based approach?

TABLE OF CONTENTS

1. INTRODUCTION

After the Fukushima Daiichi accident a number of initiatives have been undertaken internationally to learn from the accident and to implement lessons learned to improve nuclear safety. The accident has shown the challenges in supporting reliable human performance under extreme conditions. NEA members believe that further investigations are necessary to improve and disseminate experience and knowledge about human and organisational factors (HOF) that influence human performance under extreme conditions.

Expected human activities during accidents management and mitigation include recovery actions in and out of the control room or plant such as repair of structures, systems and components and crisis management. Extreme conditions are characterized by one or more of the following event attributes:

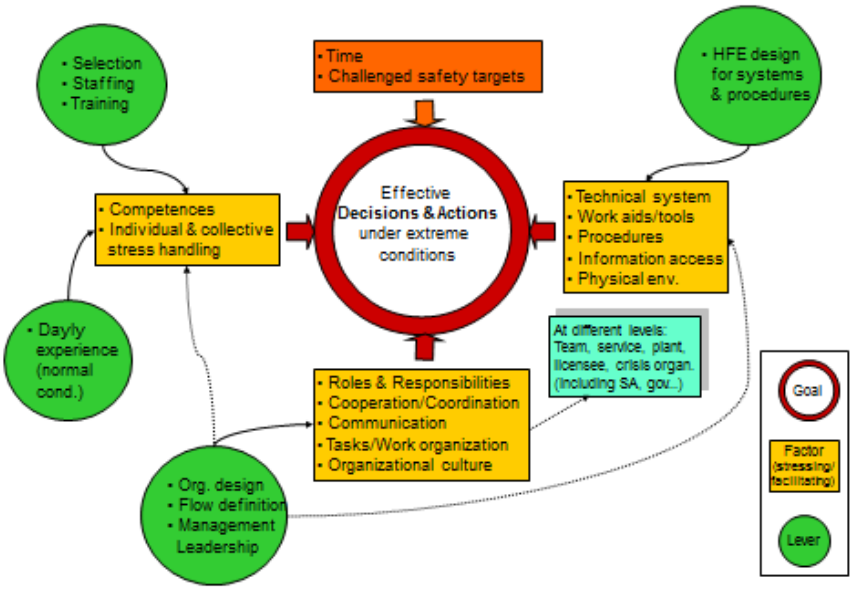
- unexpected , not covered by training or procedures;
- beyond design basis, loss of safe guards and safety barriers;
- dynamic that are rapidly changing, escalating or accumulating;
- insufficient and unreliable information;
- complex and potentially long term duration;
- challenging the organisation (on site and off site);
- potential adverse health consequences including loss of life.

The international community already has well-established approaches in the HOF area that support reliable human and organisational performance, but these are principally focused on the design process for normal or "within design" basis events. As the Fukushima Dai-ichi accident underlines, the HOF challenges may differ during more complex beyond design basis events.

Figure 1 is a model of HOF areas influencing human performance under extreme conditions. Effective decision making and actions depend first on the specific consequences of the event (e.g. available time, challenged safety targets) defining requirements for and limitations of human interventions. Assuming a beyond design basis accident the quality of precautions in the following three HOF areas are contributing to the possibility to prevent or mitigate severe consequences:

- **Human capabilities** (e.g. availability of competencies, individual and collective stress handling).
- Provision of necessary **infrastructure** taking into account human factors engineering (HFE) aspects of the technical systems, work aids and tools, procedures, needed information and physical environment.
- **Organisational** aspects such as defined roles and responsibilities, cooperation and coordination, communication, task and work flow, organisational culture. Multiple organisational levels and entities should be considered to include the broad system of actors coping with an extreme event (e.g. government and regulatory bodies, the licensee organisation, and the operating/plant (site) organisation).

Figure 1: **HPEC impact model**



The overall aim is a resilient coping with the extreme situation. Appropriate provision of and within these listed areas will enable and support individuals in their decision making and action performance. Design deficiencies will cause increased stress, delay or failure of the necessary emergency response. The quality of these areas depends on and can be leveraged by HOF design measures affecting elements within these areas such as staffing and staff selection, training, organisational structure, leadership, procedures, access to plant and information, and means of communication.

Acknowledging that further work is needed to be better prepared for the HOF challenges of the extreme conditions that may be presented by severe accidents, the NEA/CSNI WGHOF initiated a new task with the objectives to:

- share experiences and knowledge of human and organisational performance under extreme conditions,
- identify specific currently applied HOF principles in nuclear and other high risk industries and compare them with the available knowledge,
- provide a basis for improvements and necessary research taking into account HOF issues in the design and use of measures, and
- Make recommendations with the aim to achieve the best level of human and organisational performance as possible under extreme conditions.

The investigation results of the Fukushima Daiichi accident revealed that deficiencies in almost all organisational levels contributed substantially to the Fukushima accident progression and the extension of its consequences. The results also pointed toward resilience as organisational factor warranting deeper consideration. As a result, WGHOF identified “resilience” as a construct with a potentially deep and broad applicability to this task.

In the light of these considerations the following key questions were investigated as part of this task:

- How should competencies, division of authority and responsibility be designed in order to promote effective and resilient performance at the individual, group and organisational level assuming reduced resources and increased threats to organisational integrity?

- Which measures to promote human and organisational performance in accident situations are under development or have already been implemented in nuclear and other high-risk industries?
- What guidance can be taken from scientific research and what are the still existing knowledge gaps?

In order to move those issues forward the CSNI working group on human and organisational factors hosted together with the Swiss Federal Nuclear Safety Inspectorate ENSI a workshop entitled "Human Performance under Extreme Conditions with respect to a Resilient Organization". The workshop took place in Brugg, Switzerland in February 2014.

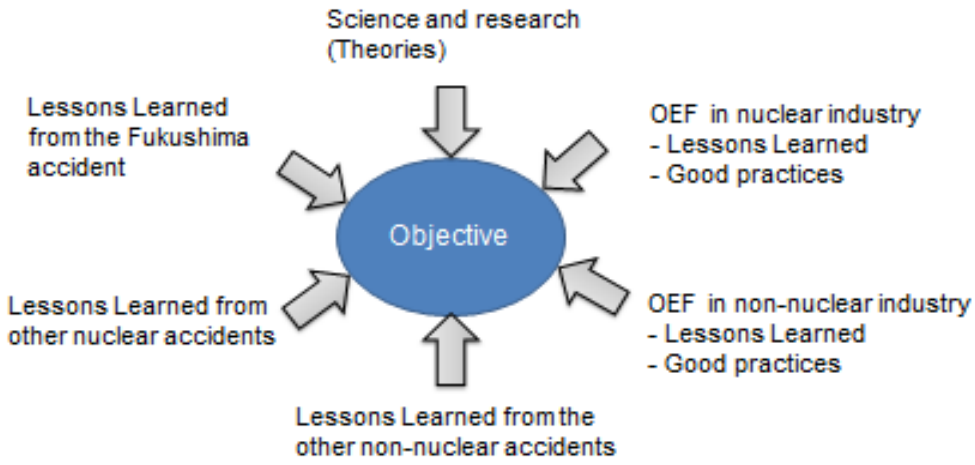
The workshop was conducted with participation of a number of invited key speakers from academic research and a range of industries, including nuclear. Thirty-four experts from 12 countries and IAEA and OECD/Halden participated. Experts came from nuclear authorities, research centres, technical support organisations, training simulator centres, utilities and from non-nuclear field (aircraft accident investigation, firefighting, military, design of resilient organisations).

The members of the WGHOF task group reviewed all obtained information in order to identify good practices, or knowledge gaps as well as to provide a basis for promoting improvements and further research. This report describes those activities as well as findings and conclusions according to the objectives of the task and the workshop. Participant input is recorded in the report largely in the form it was presented by the participants in the workshop.

2. SCOPE, OBJECTIVES AND STRUCTURE OF THE WORKSHOP

The objective of this international workshop was to provide a forum to exchange information on how to achieve effective and efficient human performance and a resilient organisation facing a nuclear accident with extreme conditions. In particular, what are the key enabling factors, how do they contribute to the objective of accident management or mitigation, and how can they be improved or leveraged? In order to achieve the objective knowledge has been sought both from nuclear and non-nuclear fields. Experts from different disciplines, such as the military and emergency first responders provided their practical experience concerning a broader view on the human performance in extreme conditions. Figure 2 presents the different areas of expertise considered at the workshop.

Figure 2: **Considered expertise resources**



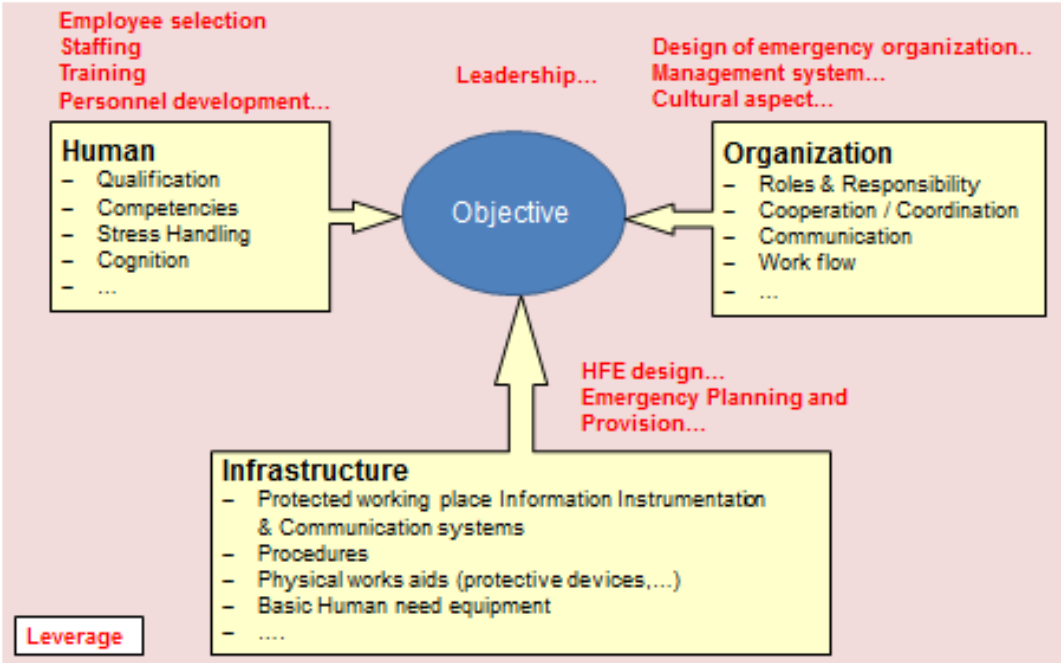
With respect to the HPEC impact model (see Figure 1), the workshop was structured into an opening session dealing with the target setting followed by three technical sessions on human, organisation and infrastructure. Scope and content of the technical sessions as well as their relation to the general workshop objective is shown by Figure 3.

Within the four sessions the following plenary presentations (see Chapter 5) were provided:

- Session 1: Introduction and scope, Fukushima
  - Human Performance under Extreme Conditions – The Challenge of the Extreme (Jean Pariès, Dédale)
  - The Dynamics of Leadership under Pressure (Major Russell Lewis, United Kingdom)
  - Operational Experience in Emergency Response and Crisis Situations (Colonel Bertrand Domeneghetti, Mission d'Appui au Risque Nucléaire)
  - HOF Lessons Learned so far from Fukushima (Ryuji Kubota, JNES)
  - HOF analyses on the Fukushima Nuclear Power accident (Cornelia Ryser, ENSI/Elsa Giquet, IRSN/Monica Haage, IAEA)

- Session 2: Human factors
  - Understanding behaviour in severe accidents
    (Jon Berman, Greenstreet Ldt)
  - The right stuff: Personnel selection, training & treatment of Swiss Air Force pilots
    (Andrea Lohse & Philip Noser, Swiss Air Force – Psychological Service)
  - Lessons learned from nuclear emergency exercises and implications for organisational resilience
    (Mandy Richter, ESN)
- Session 3: Organizational factors
  - Organizing for the unexpected
    (Kathleen Sutcliffe, University of Michigan)
  - General organisational aspects and safety culture
    (Toni Waefler, FNHW)
  - Design of an NPP emergency organization
    (Wolfgang Hösel, Swiss NPP KKL)
  - My personal experience from the 2004 Tsunami in Thailand
    (Major Alf Ingesson Thoor)
- Session 4: Infrastructure
  - Organization of emergency preparedness and response in Germany
    (Oliver Wilhelm, EnBW NPP)
  - Resilient procedure use – Compliance and resilience in complex EOP scenarios
    (Michael Hildebrandt, Institute for Energy Technology, Halden)
  - Can procedure-based practises support coping with the unexpected – Concepts and empirical results
    (Leena Norros and Paula Savioja, VTT)

Figure 3: **Grouping the range of topics into three technical sessions**



In order to provide the possibility of a more active involvement of the workshop participants and to broader the available information basis the technical plenary sessions were accompanied by breakout

sessions. In the context of small group discussions each identified recommendations for addressing the topic as well as knowledge gaps, challenges and research needs. Breakout sessions to the following topics were conducted:

- Stress and cognition
  (Session 2, Topic 1),
- Training and exercise
  (Session 2, Topic 2),
- General organisational aspects
  (Session 3, Topic 1),
- Leadership, management, cultural aspects
  (Session 3, Topic 2),
- Comparing existing strategies for emergency preparedness, methodology and tools
  (Session 4, Topic 1).
- Procedure usage and design
  (Session 4, Topic 2)

The next section of the report provides a summary of the plenary papers and the five breakout sessions.

3. PLENARY PRESENTATIONS AND WORKSHOP SUMMARY

3.1 Plenary presentations

3.1.1 Session1, Part 1: Introduction and scope

Human performance under extreme conditions – The challenge of the extreme (Jean Pariès)

Mr. Pariès provided an overview of the current safety paradigm. The typical approach is to perform an exhaustive assessment of potential scenarios and predetermine the responses, which can be embodied in a safety case. Following an unanticipated event, the safety case is typically extended to include more predetermined responses, which may in fact make it more difficult to respond to further unanticipated events. Another aspect of the current safety paradigm is to define risk as frequency X consequence, and to assume that it follows a normal curve. He asserted that this results in some assumptions or treatments that may not be strictly correct:

- Equivalence: low-frequency/high-consequence events are treated the same as high-frequency/ low-consequence events, but in fact society may not accept the high consequence event, whereas the low-consequence event is regarded as acceptable.
- Prediction: putting in place good processes for high-frequency events is regarded as helping to prevent low-frequency events, when there may be no correlation.
- Small tail: the frequency of high consequence events may be under estimated, if the event distribution is assumed to have a thin tail (i.e. high consequence events are rare) when in fact they may have a "fat tail" (occur with greater frequency than originally estimated).

Mr. Pariès suggested that rather than focussing on making systems more reliable (the current paradigm), systems should be made more resilient, that is more able to respond to disturbances, including extreme conditions. This requires fundamental shifts in thinking; to a decentralized and empowered organisation; to reducing predetermination and providing for dynamic replanning; and to management of diversity and maintenance of response capability. This requires reserve capability and duplication and therefore may be less efficient. He noted that the associated paradigm shift will require societal acceptance, particularly of the uncertainty of the response (we do not know what the response will be, but we do know there will be a response) and of less focus on personal accountability for actions or inactions (because there are fewer predetermined actions).

The dynamics of leadership under pressure (Major Russell Lewis)

Major Lewis described a personal leadership challenge from a tour of duty in Afghanistan. From experience, he drew a number of observations and lessons in response to challenging events:

- Leadership: Leadership is required at every level, and it needs to be values-based. There will be constant frictions, but a leader must retain a focus on the objective. The objective and associated decisions must be communicated effectively.

- Decisions: Leaders need to make decisions, and need to be in a position of influence to affect those decisions. That means in the right physical location to understand the situation, but not in the way of effective implementation. This also means in a position of trust, and that trust has to be earned.
- Judgment: Leaders need to have the moral courage to make the right decisions, not necessarily the popular decisions. They also need to understand the difference between what needs to be done versus what people may want to do.
- Teamwork: Teamwork is essential to effective response to challenging events and the response will be only as effective as the weakest link. In that regard, people will always surprise you, both positively and negatively.
- Training: You have to train thoroughly and as realistically as possible. In a stressful situation, you will revert to your training. Training will also help with selection, although there will still be surprises.

Major Lewis closed with the observation that perhaps reliability is associated with good management and resilience is associated with good leadership

Operational experience in emergency response and crisis situations (Colonel Bertrand Domeneghetti)

Colonel Domeneghetti provided some of his observations and experience from the French Government's General Directorate for Civil Protection and Crisis Management. He provided specific examples of events where well-trained and qualified individuals made poor decisions. In those events, there were confounding factors such as family situations and experiences with similar events that may have contributed to the individual's response.

Colonel Domeneghetti went on to stress the importance of interfaces:

- Diverse response teams: Response teams are typically diverse, involving people from different organisational groups, or different organisations. These people can use different technical language and different response processes. One way to address this is to ensure that teams receive common training and take part in exercises.
- Plans do not reflect reality: Emergency plans are often created with an idealized view. For example a 2 km evacuation zone is shown as a circle. In reality, if the boundary cuts through a municipality, the local authorities may choose to evacuate the whole municipality. Similarly, people along an evacuation route may choose to evacuate as well, even if beyond a nominal boundary. It is therefore important to ensure that interfaces to key off-site organisations and decision makers are established and used to test and improve plans.
- Social media: Social media is making informal communication more prevalent than formal communication. The messages from social media are quicker and reach further. This can undermine the communications aspects of an emergency plan.
- Regular media: Regular media can create the wrong impression and lead to improper responses to an event. The volume of their requests can also overwhelm response staff. The media will tend to be seen as authoritative, leading subsequent emergency response communications to be regarded as biased.

3.1.2 Session 1, Part 2: Fukushima

HOF lessons learned so far from Fukushima (Ryuji Kubota)

Mr. Kubota provided a summary of the lesson learned from Fukushima from a Human and Organizational Factors perspective. He stressed the wide variety of decision modes exhibited by people in responding to the accident. In particular he noted the "sacrifice" decisions (i.e. decisions that put individuals and co-workers at risk) that are necessary at times when the conditions were not conducive to good decision making (e.g. family members affected and personal comfort compromised). He also highlighted the social challenges with decisions around venting the reactor containment and permitting radiological releases to the sea, and how these decisions were made with or without the right organisational and governmental support. Mr. Kubota described some of the differences in the responses at Daiichi and Daini, where combinations of available mitigation capability, and good decisions in exploiting this capability, enabled Daini to avoid the severe accidents seen at Daiichi. He also talked about the examples of group think, elite panic and micro-interventions seen during the evolution of the accident and how they contributed to the response. Some of the immediate observations are the importance of training and drills in inculcating good behaviour, and the importance of establishing decision making responsibilities and processes in advance.

HOF analyses on the Fukushima nuclear power accident (Cornelia Ryser, Elsa Giquet, Monica Haage)

Ms. Ryser informed participants that ENSI was updating their analysis of the HOF aspects of the Fukushima accident that had been published in 2011. She then stressed the aspects of Fukushima that contribute to its overall complexity. The conditions of the physical environment were harsh. There were many challenges to physical and psychological well-being of the response staff. The accident involved parallel, but different, severe accidents in multiple units, and with overlapping responsibilities for staff in response. The response to the accident required a broad range of organisations and individuals. Lastly, the lines of responsibility were not clear. Ms. Ryser expressed the view that the event was a fundamental surprise, and not a situational surprise. She defined fundamental surprise as a "sudden revelation that one`s perception of the world is entirely incompatible with reality" and situational surprise as "events temporally unexpected, but their occurrence and evolution are generally explicable and compatible with basic beliefs" (see page 13 of the presentation). She concluded that we need to question the current safety paradigm and ensure the fundamental lessons are learned. In particular, we need to understand the cultural mechanisms that contributed.

Ms. Giquet described work underway at IRSN to look at the HOF aspects of specific actions taken during the Fukushima accident. One of those was the decision to pursue fire engines for emergency water injection instead of trying to restore an existing system – the isolation condenser or the diesel driven fuel pump. She outlined the contributing factors to the decision – lack of, and conflicting information available on the existing systems; challenges with radiation fields; and availability of procedures and staff with appropriate technical capability. Her overall observation was that it is not necessarily faster to restore lost capabilities compared with developing new capabilities, and therefore it is not clear how long one should persist in attempting restoration, nor how to address the reluctance to try an alternate approach.

Ms. Haage outlined the work being performed by the IAEA to document the HOF aspects of the Fukushima accident in the IAEA's comprehensive report that was being written at the time of this workshop. She outlined the process that was being used, which was built on the IAEA's safety culture assessment methodology. A large database of facts had been assembled and verified. The report was expected to cover about 5 over-arching themes, but these will only relate to a fraction of the information assembled. Nevertheless, she believes that further information will be required to really understand what happened, particularly interviews with responders and other key people in Japan.

3.1.3 Session 2: Human capabilities

Understanding behaviour in severe accidents (Jon Berman)

J. Berman contrasted our understanding of human performance during normal operations with that during severe accidents. He noted that although knowledge-based behaviour is avoided during normal operation as unreliable, it is expected during emergency operations yet we do not have the appropriate models and necessary support tools. In particular, high stress situations may change the nature of error types. He believes that the response to high stress is typically indecision and that people respond to the unexpected by looking for similarities to previous experiences and adjusting. Preplanning, proper selection and training, use of high-validity exercises, ensuring resource availability, etc. can all improve response. Additionally, useful interventions are to ensure good team dynamics, provide strong leadership, and reduce anxiety. Mr. Berman concluded by noting we have knowledge gaps in the limits of application of our current models, whether we really optimize for severe accidents, applicability of our HRA methods, how to account for the surprises that people will bring, new error modes, and the effects of long-duration events.

The right stuff: personnel selection, training and treatment of Swiss Air Force pilots (Andrea Lohse and Philip Noser)

Ms. Loshe and Mr. Noser described a very robust process used by their institute to select, train and support Swiss Air Force pilots (and some other key positions such as commercial pilots). The starting point is a thorough Fleishmann job analysis to determine the key characteristics. Alternating rounds of training and assessment are then used to help candidates develop the right expertise and to select candidates who were capable of continuing to the next round. Screening is based on psychological and capability assessments, in a range of environments, including those as close to the expected work environment as possible. As a result, the institute is very successful in identifying and training people who are ultimately capable of performing well. The institute can also then provide fitness for duty assessments, and provide support to pilots who suffer challenges during their careers. Ms. Loshe and Mr. Noser concluded that their institute's success was built on being clear on what they were looking for; measuring performance under a range of conditions, including work-related; and using an integrated process with feedback loops.

Lessons learned from nuclear emergency exercises and implications for organisational resilience (Mandy Richter)

Ms. Richter outlined experiences and lessons learned from the emergency exercises at German nuclear plants overseen by ESN. A typical exercise would last for 2.5 to 6 hours, and involve from 80 to 150 participants and 6 to 12 observers. From the exercises, they have observed good practises in techniques for visualizing the event and sharing, and in clear rules for transitioning responsibility. In terms of improvements, ESN is considering exercises that run to several days, and perhaps involve multiple units and on-site interim storage. Ms. Richter concluded that there are indicators for resilience in emergency planning and exercises, and that the following factors enhance resilience:

- implementation of recommendations for exercises and planning; and
- independent analysis of emergency planning and exercises

3.1.4 Session 3: Organisational factors

Organising for the unexpected (Kathleen Sutcliffe)

Ms. Sutcliffe provided a summary of some recent research on characteristics of a resilient organisation based in part on observations from fire-fighting teams for wild land fires. The underlying premise is that facing increasingly dynamic and uncertain environments, organisations must develop capabilities to adjust and adapt.

In that regard, a key capability is "sense-making" – the ability of an organisation or leader to assess an ongoing situation and create the context for action – "What's the story and now what?" Sense-making occurs when individuals interpret a flow of experiences into words and categories and then use it as a springboard for action. A number of cognitive activities are contributing to the sense-making process (e.g. conscious or unconscious search for information and interpretation patterns, diagnosis, decision making). Often some form of impetus or disruption is required to cause a response team to review the situation. To avoid the situation "no new impetus – no new sense-making" organisations must continually update their "story" through rapid, frequent sense-making. Organizations and teams can become too involved in an ongoing series of actions and fail to see that the overall situation warrants a different approach (example of firefighters who are engaged in a localized activity and fail to recognize the progress of a fire and become over-run).

Another key capability for adjusting and adapting is "anomalizing" – paying attention to details, recognizing discrepancies and addressing them before they become larger issues. A challenge in that regard is how to "anomalize" in a rapidly changing event. This can perhaps be achieved with good communications practises, and regular stop-points to review and revise.

Ms. Sutcliffe concluded by providing the following observations:

- processes are required to "unsettle" organisations to increase alertness and awareness,
- organisations should create and foster capabilities for sense-making,
- frameworks of understanding are required, incorporating detail, but avoiding over-simplification – detail is required to manage the unexpected,
- anomalizing and sense-making are key practices for resilience.

General organisational aspects and safety Culture (Toni Waefler)

Mr. Waefler provided some observations on organisational aspects of resilience and safety culture from examining work processes in railway operations and manufacturing. He noted that explicit goal formulation and communication are required competencies for organisational resilience. Further, there are formal and informal communication processes. The formal processes typically come from organisational design and work procedures. Informal processes arise as people work and interact on and off the job. In some cases, the informal processes can be very important for building resilience through better understanding of context and goals, and through building redundancy (e.g. train drivers, controllers and maintainers who monitor radio communications to gain a sense of the overall situation and how it is changing). A core aspect of organisational resilience is balance – balance between centralization and decentralization; balance between rigidity and flexibility; balance between discipline and agility. Mr. Waefler concluded by observing that culture can be both an enabler of resilience and a disabler. It can build trust and provide coordination and integration. On the other hand, a strong compliance based culture can inhibit flexibility and creativity.

Design of an NPP emergency organisation (Wolfgang Hösel)

Mr. Hösel described the emergency response organisation used at the Leibstadt NPP. The overall goals are to protect the public and environment, the plant personnel, and the plant – in that order. The core to the emergency response organisation is the team in the control room managing the reactor and working autonomously within a predefined range of responsibility. They are supported by an on-site emergency response or crisis team that has representatives for key support infrastructure or capability such as power, chemistry, radiation protection, communications, etc. This emergency response team is responsible for

goal-oriented middle and long-term coordination of resources. Offsite, there is a local response organisation responsible for actions such as sheltering or evacuation. Some of the key features are:

- redundancy and diversity of key functions such as power, control and response centres;
- roles and responsibilities are clearly established in advance;
- clear lines of communication are required on-site and off-site;
- there has to be a range of training, exercises, drills and simulator training. Drills, in particular, are valuable for ensuring effective action during the initial phases of an event which is typically quite chaotic;
- The transition from prevention to mitigation brings with it a transition in lead from the control room to emergency response team.

It was noted that a particular challenge is establishing and testing communication lines to neighbouring countries

My personal experience from the 2004 Tsunami in Thailand (Major Alf Ingesson Thoor)

Mr. Thoor shared his experiences providing psychological support to Swedish and other citizens following the devastating tsunami in 2004. The disaster was the result of a 9.3 Richter earthquake and tsunami with about 300 000 fatalities. Mr. Thoor was dispatched with a team to help Swedish citizens. Some of his observations were:

- When you are overwhelmed, your body protects you by reducing inputs, so you retreat into a bubble and may not respond appropriately.
- Even when facing tragedies of their own, people will often still help others.
- The media arrive very quickly, and it is best to be proactive. If you can engage them, they can sometimes help you get your messages out.
- Over time, helpers become victims as they are continuously exposed to the horror and devastation – they need psychological support.

3.1.5 Session 4: Infrastructure

Organisation of emergency preparedness and response in Germany (Oliver Wilhelm)

Mr. Wilhelm provided an overview of the emergency preparedness and response and how it fits into the overall safety structure of a nuclear plant. Nuclear safety is built on three basic functions: control the nuclear reaction, maintain cooling for the fuel, and contain the fission products. He noted that typically four states are considered for a reactor: normal operation, anticipated operational occurrences, accidents within the design basis and beyond design basis accidents. For the last state, two sub-states can be defined: accidents without and with core damage. It is this last sub-state that constitutes a severe accident. A defence-in-depth approach is used for nuclear safety with a focus on redundancy and diversity to ensure reliability.

With this background, Mr. Wilhelm described some of the main features of emergency preparedness and response in Germany. As described earlier by Mr. Hösel, there is an on-site crisis management team, led by the unit manager. The unit manager has clear autonomy for decision making during the accident – no approvals are required from off-site. The local government is responsible for establishing response capability to address any off-site consequences. Germany has put in place a depot of response equipment, including equipment for communications, radiation protection, back-up power, etc., that can be brought in to supplement on-site capability. In answer to a question, Mr. Wilhelm said that there has not been much formal consideration and pre-planning for multiple unit failures in a region.

Resilient procedure use – Compliance and resilience in complex EOP scenarios (Michael Hildebrandt)

Mr. Hildebrandt summarized some of the work being performed under the Halden Reactor Project on resilient procedure use. He noted that new (disruptive) technologies such as smart mobile devices are changing the way we work, and concepts such as integrated operations provide opportunities to bring additional resources to bear in unexpected events. Mr. Hildebrandt then went on to discuss some of the tests being performed in the HAMMLAB that are revealing aspects of good and poor procedure use. Resilient procedure use requires a good balance of heads-down operations (e.g. carefully following a procedure) and heads-up operation (determining what is happening). Some of their general observations from the HAMMLAB tests are there can be significant variability between crews, knowledge-based decision making is difficult, crews can get tired after ~1 hour of trying to making sense of what is happening and if a crew gets "stuck" it can be difficult to recover. In particular, a Special Technical Advisor (STA) to a crew can be good resource if the STA maintains a good level of independence to help prevent the crew from getting stuck.

Can procedure-based practises support coping with the unexpected – Concepts and empirical results (Leena Norros and Paula Savioja)

Ms. Norros and Ms. Savioja provided an in-depth summary of their work on how procedure-use can contribute to the response to unexpected situations. Background on the need to balance stability and flexibility in providing safety management was described. Then VTT's studies on procedure use were outlined, based on a model with three aspects:

1) orientation is the basic assumptions and underlying principles;
2) procedures are the rules that embody the principles; and
3) the habits of action are the way in which operators typically execute the procedures.

In the VTT studies, the use of procedures by a variety of crews was observed and the orientations and habits of actions characterized as interpretative, confirmative or reactive. Overall, crews were found to be mostly in a confirmative mode, with interpretative and reactive modes being secondary (and roughly equal in occurrence). Ms. Norros and Ms. Savioja concluded by observing that a better understanding of how procedures are used should be factored into procedure design and training.

3.2 Summary of plenary presentations and breakout discussion

The Fukushima accident was a fundamental surprise challenging the assumptions and decisions made in the past:

- Design of plants and emergency preparedness is a result of decisions taken many years before.
- Decisions concerning design, back-fitting etc. taken on the background of deeply rooted beliefs and assumptions in organisation, industry and society.
- Complex network in Japanese industry.

Personnel were impacted by a harsh environment (e.g., loss of power, radiation, lack of tools, fatigue, personnel hygiene) and psychological factors (shock, uncertainty, disbelief, fear, lack of understanding how to interpret physical indications).

Severe accident management makes demands on operators such as prevention of escalation, mitigating consequences and achieving a long-term stable state. But what do we know about how people will behave in a severe accident and how do we judge resilience and preparedness? The challenge of the extreme is also challenging our current safety paradigm which relies on:

- anticipation of all potential situations (exhaustive, deterministic and probabilistic assessment), and
- risk is deviation from the expected.

Usual responses to the unexpected are more predetermination (e.g., more procedures, better technical reliability, and more automation) and more authority to the control processes (i.e., more constraints on front line operators and more authority to automated protections). There is a linear vision of risk but there are signs of strategic weakness.

- Inductivity illusion: Our accident model is incomplete and there might be no correlation between frequency of low severity events and extreme events.
- Rationality illusion: Risk is defined mathematically as the product of probability and amount of damage but for extreme events the product is not a criterion for social acceptance.
- Thin tail illusion: The frequency of extreme events might be higher than calculated.
- Continuity illusion: Coping with extreme events is not merely an extension of deviation management.

Emergency response brings together professionals from different (technical) worlds speaking different languages. Standards might not be the priority and more flexibility is needed. Further development of resilience design principles is the path forward to improve emergency responses in extreme situations. The workshop was structured to investigate three topics which impact human performance as described by Figure 2: Human capabilities, organisation and infrastructure. The following sections summarize the plenary presentations, group discussions and any knowledge or research gaps identified.

Human capabilities

Presentations

Severe accident management makes demands on personnel and there is evidence from operational experience that people "save the day." We rely on human performance, but people are dynamic (e.g., use pattern-matching, are creative) and are sensitive to performance shaping factors especially stressors. Much analysis is about assessing the predictability of performance. In the context of a beyond design basis accident specific behaviour models and error types (e.g. denial, freezing, poor cognitive performance, further impacts of high or threat stress) should be applied. A number of factors will impair performance:

- limited procedure guidance (implies operating knowledge-based),
- insufficient, excessive or unreliable information,
- fundamental shock, threats to personal safety or safety of others, and
- compromised cognition (e.g. awareness of time, memory capability).

In order to reinforce human behaviour in critical situations it is necessary to know more about cognitive processes people are applying, if guidance by procedures is decreasing and knowledge-based behaviour including problem solving processes are increasing. RPD (Recognition-Primed Decision) is an example for an accepted model describing cognitive process (see presentation of Jon Berman and Gary Klein: "Naturalistic Decision Making", Human Factors, Vol. 50, No. 3, pages 456 to 460, June 2008). The model is combining observations from the field (e.g. military and firefighting) with findings from scientific theory. It describes how people use their experience in order to make decisions and includes sub-processes like "intuitive pattern matching" and conscious mental simulation of actions. It is able to explain observed effects like extremely rapid decision making or seeking for a "satisficing" decision (first acceptable but not optimal solution).

Options to support human performance in critical situations are:

- pre-planning of routines,
- high-validity exercises (including team dynamics, leadership challenges),

- resource availability (this includes provision of a "toolbox" of options for severe accident management and enhanced organisational support) ,
- stress-management strategies including emotional support and workload management,
- personnel selection, and
- measures to reduce shock and anxiety and to promote personal resilience.

Measures like changing social culture or removing the threat are non-options. Human strengths should be developed by:

- designing normal work arrangements to train the skills for dealing with any situation,
- avoiding "automating away" needed skills,
- understanding types of creativity(i.e., adaptive or innovative),
- supporting sense-making, anomalizing (see presentation of Kathleen Sutcliffe), hypothesis formation and testing, and
- understanding the strengths and limitations of pattern-matching.

Most of our arrangements and training are focused on normal operations and moderate probability events. We prepare for the expected but we should expand that (preparation "to be unprepared").

Group discussions

Stress reduces flexibility. People tend to prefer well known explanations and decision patterns. A new kind of human factors engineering is requested to keep people flexible in grave emergencies. Different measures are taken into account to reduce stress impacts. As far as stress and cognition are concerned, the following key factors have been identified:

- Strategies of mental load control (guided by accepted models of cognition) should be provided.
- Challenges like mental fatigue, reduced situational awareness (e.g. due to degraded amount of information), reduced cognitive capabilities (memory, search for explanation and action pattern, prediction of event development) and handling of interruptions (to wait) should be considered.
- Organisational preparedness shall include improvisation capabilities. In order to be flexible during emergencies it is necessary to be flexible in normal situations too. That challenges the current safety paradigm. How does a compliance culture (e.g. strictly follow the procedures) allow for the development of flexible response?
- It is important to have external people like stress managers on site (e.g. monitoring cognitive performance of emergency response team).
- Organization shall be prepared for "mental fatigue" (e.g. back-up staff), problem solving difficulties (e.g. time limit when crew is "stuck") and reduced memory capabilities (e.g. provision of checklists and automation).
- People develop different behaviour during emergency situations. Training measures especially for leadership roles should take this into consideration.
- Leadership and organisational structure will need to evolve during an event. A resilient organisation should recognize and enable this.

The following key factors of severe accident training and exercise were identified:

- shift of decision making authority,
- use of support tools (e.g. charts),
- handling of uncertainty and resilient (creative) use of procedures (including transition between the two approaches) as new training/exercise objectives,

- learning from exercises by detailed debriefing sessions,
- changing selection and qualification requirements should be considered, (e.g., plant management should have the capability to cope with stress),
- do not focus on selecting the superior performers but rather look for the absence of weakness,
- due to limited available resources frequency and effectiveness of exercises and training should be evaluated (this includes use of different training and exercise locations like control room, simulator and outside in the field),
- training and exercise scenarios should be as realistic as possible (e.g. including dynamic aspects or problems with contradictory information). and
- the limits of "realistic" training and exercise should be considered. In order to simulate emotional burden and threats ethical limits have to be accepted. To avoid "loss of trust in the system effects," a trade-off between illusion and trust should be found and reflected within the debriefing sessions.

Knowledge gaps

The following knowledge gaps were identified:

- Stress research has remained an individual topic; it has not been integrated into cognitive psychology yet.
- Distributed/embodied cognition is not reflected in research models. When you are able to be in touch with other people (connectedness) you may be more capable of dealing with stress.
- Importance of person/person interactions for reducing stress should be considered.
- "Are experts who are highly trained facing the same amount of stress as non-experts?" versus "Stress is driven by your perception of the situation, so experts are able to feel stress as much as non-experts."
- Relationship between compliance and resilience (i.e., from a cognitive point of view) should be further investigated.
- What is the impact of sacrifice decisions, non-compliance and legal responsibility?
- We need to know more about impact of non-homogeneity of people.
- What is the impact of stress management on cognition?
- Ethics – how far can we go and should we go to make exercises as realistic as possible (e.g. incorporate emotional stress in trainings and exercises)?
- Learning from exercises – how can they be useful for the plant as well as proof of performance. How can necessary changes be implemented. Should limits of the exercises be explained in the debriefing? Can training to failure undermine human performance and learning?
- How and should existing simulators be used in severe accident training? Are charts good enough for exercises? Are we simulating the right things? Are there fidelity issues?
- Should field/local tasks in harsh environments be simulated (train with negative performance shaping factors)?
- Can severe accident training be integrated with existing training because of time limitations/burden on operators? What about frequency of training and effectiveness?
- Transition from a rules based approach to a knowledge based approach should be further investigated (need to understand it; manage it; organise for it).
- How to ensure that exercise scenarios are both credible and are challenging the emergency response organisation (e.g. long-term accident)? Is it worth to provoke final failure when designing an exercise?

Organisation

Presentations

Managing the unexpected requires the development of highly reliable organisations which mindfully organise:

- a social context of trust and respect,
- processes and practices that successfully unsettle organisational routines to increase alertness and awareness and further create capabilities to make sense and to cope with what is seen,
- coordination mechanisms to help people and teams to become aware of what is happening upstream and downstream from their individual roles, and
- ongoing practices and routines aimed at:
  - tracking small failures (preoccupation with failures, sensitive to operations),
  - resisting oversimplification,
  - being sensitive to what is happening right now,
  - taking advantages of shifting locations of expertise and to defer to expertise, and
  - developing capabilities for resilience.

Success belongs to organisations, groups and individuals who are resilient in the sense that they recognize, adapt and absorb variations, changes, disturbances, disruptions, and surprises (especially disruptions that fall outside of the set of disturbances the system is designed to handle). Resilience is defined as the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances under both expected and unexpected conditions (Woods and Hollnagel 2006; and Hollnagel 2011, see presentation of Toni Wäfler).

All complex adaptive systems strive to manage a balance between their degree of specialization, and their robustness outside their adaption envelope. The more a system is "fit" (optimized for a given environment), the more sensitive it will be to disturbances. A trade-off between optimality and fragility is needed. Organizational resilience comprises the following generic competencies:

- information management (explicit goal formulation, sort and prioritize),
- effect control (e.g., understand and learn from past events, including updating goals and process, and monitoring short-term developments to anticipate long-term potential threats and opportunities),
- communication and coordination (roles and responsibilities, balancing flexibility and rigidity), and
- decision making (e.g., distributing the decision making process).

Managing the unexpected requires departure from the traditional management vision. Often unrecognized is that resilience can also develop through the evolution of an organisation over time by development of informal lines of communication and coordination. More detailed characteristics of resilient organisations are:

- recognition of the need for local autonomy (polycentric governance, under-specification, management of trust and confidence, shared values),
- institutionalized management of margins of manoeuvre (requisite imagination "what if", weak signals, sentinel events, stop rules),
- dynamic re-planning, priority changes, reallocation of roles, sacrificing decisions capacity,
- management of adaptive competence/expertise,

- bricolage (e.g., the ability to create what is needed at the moment out of materials at hand), and
- management of oversizing, slack, buffers, stocks, back-ups, bunkers, etc. (anti-lean management).

Managing the unexpected implies two organizing practices, anomalizing and leader sense-making, which should be promoted by a resilient organisation.

Sense-making is the act of assessing an ongoing situation and giving meaning to organisational action. Sense-making occurs when individuals interpret a flow of experiences into words and categories and then use these as a springboard for action. It is typically triggered when people experience a breech in expectations.

As groups coordinate and organize, there is a tendency to "normalize" action and events (e.g. simplify, smooth, and incorporate). To "anomalize" is to capture unique particulars of an event (i.e. differences, nuances, discrepancies and outliers). Anomalizing helps groups continuously update diagnosis and decision making.

For extreme events management, a proper account of complexity science would suggest a significant paradigm shift:

- Expanding control strategies from the past (anticipation, predetermination).
- Changing control structures from centralized hierarchies to distributed networks. Culture may serve as a centralization mechanism in a decentralized organisation. Problems occur, if the required flexibility is not part of the culture.
- Recognizing the limits of analytical rationality to generate by itself acceptable solutions.

Group discussions

One of the key issues is the question whether and how compliance and resilience design principles can be combined. Up to now emergency concepts are organized very strict and defined. Resilience is a totally new concept for nuclear power plants. Obviously it is not possible to be compliant and resilient at the same time. Participants stated that it is necessary to go "outside" to know what resilience is in detail and how it can be transformed to nuclear organisations (e.g. connecting points between compliance and resilience principles). Resilience includes:

- capability to improvise within the organisation (space for creative thinking),
- to know who is an expert for what, to trust their decisions but to keep a questioning attitude,
- use of different (redundant) teams working on the same problem but with different points of view (could compensate decreasing problem solving capabilities but what happens when one team is more compliant than the other?),
- provision of decision autonomy as it is in a firefighter organisation during emergency (distributed decision making versus centralized decision making among different groups, individuals, units and the question how to coordinate that within an organisation),
- continuously monitoring the current state of operation in order to change strategies and measures (e.g. from preventive to mitigative measures). This might be supported by indicators (see below).
- to allocate responsibility to sub teams (to what extent?),
- integration of "informal" organisational structures,
- development of indicators that measure resilience capabilities and the erosion of these capabilities or to find leading indicators (indicators before the emergency state). A number of indicators are proposed (see presentation of Mandy Richter).

Regarding leadership, management, and cultural aspects, the following key factors were identified:

- Distribution of leadership in the hierarchy (consideration of military upstream – downstream principle and experience at Fukushima with voluntary decision making performed by front-line operators).
- Degree of adaption in relation to leadership in order to be resilient.
  - Collective versus individualism thinking; dialogues are changing perspectives.
  - Leaders need someone for reflection. They are usually very alone with their thoughts. Assistance is needed (and provided in military and firefighting).
- Provision of more realistic preparation which should include:
  - Management of the coordination (stay away from micromanagement).
  - Judgment where to be at the right time.
  - Being prepared to take turns to be the "top" manager.
  - Sacrificing decisions – ethical problem but capability to sacrificing decisions might be one of the key factors of organisational resilience.
  - Training of specific leadership skills for critical situations at every organisational level (e.g. to follow and adapt to the team, to take time to do the right things, self-improvement is the key).
  - Leaders role in managing the "outside" context e.g. media, politicians, local governments.
- Monitoring role for the leader.
- Cultivate a culture which allows for leadership feedback. In some cultures it is very difficult to challenge a leader's opinion and different professional cultures should be taken into account.
- Consider the role of informal leadership. Leadership changes when it comes to emergency situations.
- Consider the relation between sense making and leadership.
- Professionalism and engagement: To trust only on engagement could be a threat for people's health while professionalism can protect people from this. The connection to leadership is for leaders to monitor people's engagement. But does this really work in all cultures?
- Leadership – followership principle. Leadership depends on followership; good leadership is made by followership.
- Develop guidance and training on how to alternate the "top" management role during critical situations.

Knowledge gaps

The following knowledge gaps were identified:

- Search for the best organisational design to be resilient. Is there one best organisational design?
- Transition issues between normal and emergency organisation.
- Trade-off between compliance vs. resilience.
- Measurement of organisational resilience (leading/lagging indicators).
- Impact of informal organisation and its effect on resilience especially in severe accident given formal organisation.
- How to solve the problem of "defying superior order" in case of upstream decision making?
- How do regulators assess capabilities for resilience?

- How to integrate the resilience approach into the inter-organisational system of licensee, regulator and government?
- Informal leadership role in critical situations.
- How do we deal with cultural (national, professional) differences abilities in flexibility/resilience?
- Can experiences from other sectors be utilized in nuclear and how useful is it?
- Engagement versus professional.
- Sense making role related to leadership.
- What guidance is available for leadership in critical situations?
- Sacrificing decisions – ethical context.
- Leadership capabilities to optimize adaption in critical situations including cultivating a sound culture for leadership feedback and monitoring.

Infrastructure

Presentations

The provision of an adequate infrastructure is an essential precaution in order to cope with beyond design basis accidents. Adequate and accessible infrastructure reduces (but does not prevent) situations where people have to improvise (see Fukushima accident with the attempt to use car batteries in order to recover DC power).

Two utilities presented their approaches to be prepared for beyond design basis events (see presentations of Wolfgang Hösel and Oliver Wilhelm). The following key characteristics were explained:

- The fundamental idea is to expand the robustness of the plant to beyond design basis scenarios. Compliance driven strategies should be applied as far as possible. Specific emergency declaration criteria will facilitate the transition to a resilience oriented strategy.
- The development of their approaches was guided by feasibility considerations and included: (1) provision of a big toolbox of applicable measures, (2) exercises (including public organisations and simulation of suddenly occurring additional challenges), and (3) changes to reinforce organisational resilience. These changes include:
  - complete change of the "within design basis" organisational structure (provision of groups responsible for transportation, communication, power supply, radiation protection and decontamination, remote handling for access to areas with high dose rate, technical concerns (e.g. I&C) lead by the emergency response team),
  - allocation of responsibility and authority to the groups in order to accomplish their duties,
  - provision of work facilities and clear objectives (task allocation, task performance, cooperation),
  - application of specific safety targets (symptom and safety function based), and
  - (If possible) significant and coordinated increase of available staff (by detailed alerting guidelines) in order to run redundant activities (e.g. repair, mitigation measures).

Adequate infrastructure also comprises procedures to be used in severe accident situations. Two presentations described research efforts to find principles for resilient use of procedures (see presentations of Michael Hildebrandt and Leena Norros). Balancing pre-planned procedures and the ability to adapt to novel situations is not easy. These demands can be competing and contradictory (including negative transfers like increasing number of deviations from procedures in within design basis situations).

Focusing solely on procedural adherence may undermine the crew´s ability to make autonomous assessments, to think ahead, and to keep a high-level overview of the situation (over-reliance on procedures). Emergency response in complex scenarios requires reliability and resilience. It should be mentioned, that operator activities in many cases are resulting from a combination between information provided by procedures and the professional knowledge of the operators.

Resilient procedure use means being able to adapt the procedure to the situation if it does not fit. To respond to unanticipated situations not entirely covered by procedures crews need:

- cognitive capacity, problem solving abilities, expertise, questioning attitude,
- to understand procedure background and applicability,
- to monitor for anomalies and to predict plant evolution,
- to use background documents, and
- to avoid over-reliance on procedures and keyhole effects.

These functions degrade under high workload, complex conditions and emotional burden.

Group discussions

Infrastructure should be sufficiently flexible and specifically protected in order to support necessary resilient response of organisations facing a nuclear accident with extreme conditions. The following measures were mentioned:

- protection by distance (requirement: ability to use the outside equipment within 72 hours),
- protection by bunkering (ability to withstand big impacts, identify resources which will probably survive),
- provision of resources for resilient response and not for typical events,
- provision of strategies for instruction and guidance of external staff (e.g. specific procedures including photo documentation),
- provision of a strategy to cope with the short term period (e.g. "autonomy" conception, plant can be stabilized for a couple of hours on his own). In the course of a severe accident a lot of dramatic changes take place in the first hours. After some days the situation becomes more stable in a sense that changes can be better anticipated while the main stress situation at this time may be the radiation. So the question here is, if we should give external people more time to arrange them.
- further development of defence-in-depth conception. This includes e.g.
  - learning from Fukushima and "outside nuclear" accidents, and
  - review of basic assumptions on the frequency of the events and on the amount of impact is necessary (it is a permanent process to evaluate. Reconsider traditional ways to design emergency preparedness).
- acknowledging the problem of "limited resources." Everybody is looking for beyond design basis measures which might exceed available resources. Take advantage from improving "conventional" reactor safety measures (e.g. implementation of firefighting pumps for emergency feed water supply, measures to reduce hydrogen and to prevent containment over-pressurization by venting system), and
- strategizing for long-term events (e.g. taking into account necessary organisational changes).

Practical procedure use is related to sense making. Resilient use of procedures might improve reliability, but what could be the process of overwriting a procedure (not one single decision should kill

several analysis)? The level of flexibility in using procedures is impacting the level of trust in the procedures (how to deviate and elaborate a strategy?). The knowledge transfer to the procedures should be improved (documentation of the "knowing-why" and stronger link between training and new procedures). For whom you have a procedure depends on the culture, the ages, not everybody interprets them in the same way, depending on experience. In addition the following recommendations were made:

- Development of new procedure "philosophy".
  - Balance between stability and flexibility, level of guidance with adaptation to the actual situation.
  - Support systems for procedure usage (e.g. computerized procedures).
  - Keeping an overview while using procedures.
  - Facilitating collaboration while using procedure.
  - Managing the transition to severe accident management guidelines.
- Application of human factors expertise in procedure design and training.
  - Maintain and explicate design rationale and design basis.
  - Acknowledge that information may need to be presented in different ways according to the function and purpose of procedure.
  - Be careful with over-proceduralization.

Knowledge gaps

The following knowledge gaps were identified:

- New assumptions about impact (e.g. due to multiple or new events) should be considered.
- Review of basic assumptions on the frequency of events and of the amount of impact is necessary.
- What knowledge can we leverage from other industries (oil industry, aviation)?
- Are there direct data about practical procedure use?
- What is the process of deviating from procedure?
- Impact of trust and confidence in procedures should be further investigated.
- What do we know about interaction of reliability and resilience?
- Procedure use in practice in different cultures should be compared.
- What is adaption in procedure use and how to change to knowledge-based activity while transferring to severe accident management guidelines?
- What is the new procedure philosophy?
- What new ad-hoc organisational resources could help to increase resilient procedure-based activity?

4. CONCLUSIONS

The accident at Fukushima has clearly illustrated the challenges that can face operations and emergency response staff in dealing with a major nuclear incident. In addition to the complexities of understanding what is happening in the reactor and taking appropriate actions, people were exposed to a harsh environment (e.g. loss of power, radiation, lack of tools, fatigue, etc.) and demanding psychological factors (e.g. shock, disbelief, uncertainty and fear related to personal and family situations, etc.).

The Fukushima accident had fundamental implications for our understanding of accident management. The traditional approach to such accidents is to seek improvements in reliability that should prevent recurrence and provide staff with measures (procedures and equipment) that can be applied. The difficulty with this approach is that the increased complexity can lead to unanticipated situations that render the pre-planned responses inapplicable and ineffective. One of the fundamental conclusions from the workshop is that in addition, the focus should be on increasing resilience through improving flexibility.

Looking at this another way, all complex adaptive systems strive to manage a balance between their degree of specialization, and their robustness outside their adaption envelope. The more a system is optimized for a given environment, the more sensitive it will be to disturbances. A trade-off between optimality and fragility may be necessary.

In the following three subchapters the findings and potential areas of further work identified during the workshop are summarized for human capabilities, organisation and infrastructure.

Human capabilities

In responding to severe accidents, human capabilities pose both advantages and disadvantages. People can be very resilient – when faced with a problem, they can find creative solutions. For example, people use pattern-matching to help make sense of new situations and determine appropriate actions. At the same time, the stress associated with a severe accident can limit human performance. People can become over-whelmed and mentally fatigued leading to poor cognitive behaviour and decision-making.

Good practises:

1. Put in place pre-planned responses for the very early stages of a severe accident – e.g. preparatory activities, mobilization of resources, information gathering. This allows personnel to get over shock, gain some understanding of the situation, and start on a successful note.
2. Use realistic exercises to test and develop response capability. These are particularly important to testing lines of communication, decision-making, improvising and re-planning capabilities, leadership and team behaviour. Exercises also provide a good mechanism for developing team dynamics. An important practise to ensure that exercises are beneficial is the use of effective debriefing sessions, particularly for scenarios that had elements that could be regarded as failures.
3. Recognize that stress will be a reality and ensure that there are mechanisms for addressing stressors such as uncertainty in family situations, and that there are staff rotation plans in place.

4. Establish an observer role – a person responsible for watching team dynamics, fatigue, when, for example, teams are stuck. Such a role is important to helping make changes before stress and fatigue have an adverse impact, and when teams become stuck – too focussed on an unsuccessful approach – and need to reset.
5. Train personnel that will be in leadership roles in the requisite interpersonal and communications skills. This should include sense-making (see below).

Research needs:

- Error modes during extreme events: The existing extensive database on human error during more routine events should be built on to include what might be expected during extreme events. In particular stress research needs to be integrated into cognitive psychology.
- Extent of realism required for exercises: There are ethical considerations in the introduction of stressors and uncertainty in the benefits of pushing scenarios to failure. For example, should situations requiring sacrifice decisions be included.

Organisation

Managing for the unexpected and developing resilience requires organisations to broaden their processes. Two important attributes in this regard are the ability to understand and communicate complex situations to staff (provide a sense-making story), and the ability to recognize when the situation has evolved or the current sense-making story needs adjustments (watch for anomalies).

Ensuring organisational performance for both design-basis events and severe accidents poses a significant challenge. The organisation has to achieve a balance in centralized and decentralized processes for decision making, and a balance in a rigid adherence to procedures and a flexible response to symptoms.

Good practises:

1. Ensure that accident management teams are provided with clear lines of communication and clear authorities for distributed decision making in advance of any incident.
2. Establish an emergency management process that involves regular “stop-points” to review the current situation and determine if the plan of action needs to be revised (watching for anomalies).
3. Identify reserve capacity (people and equipment) that can be used to provide necessary flexibility to respond to the unexpected.

Research needs:

- Transition from rule-based procedures to knowledge-based approaches (compliance to resilience): Normal operations and design-basis accidents rely on rule-based procedures to guide staff actions, whereas severe accidents use a knowledge-based approach. This represents a shift in both decision-making authority and processes that would benefit from research on how to ensure the transition is effective.
- How can organisations be flexible and agile during emergencies while maintaining reliability during normal operation?
- Regulatory oversight practises for resilience: The traditional approach to regulatory oversight is to assess organisational compliance using pre-established criteria and processes. As resilience is based on ensuring flexibility, a different approach to regulatory oversight may be required. A particular consideration is what constitutes a successful exercise – is it necessary to determine what the limits are by pushing a scenario to the point of failure?
- Resilience measures: What are leading and lagging indicators of organisational resilience?

Infrastructure

The infrastructure required to respond to severe accidents includes both off-site and on-site capability. This infrastructure should include resources and equipment that is sheltered from potential initiating events (earthquakes, severe weather, etc.), and capability to move equipment to where it is needed. Specific consideration needs to be given to multiple failures that could result from a common cause – e.g. severe weather events impacting multiple units on the same site, or on different sites.

Good practises:

1. Provide redundant infrastructure and equipment (including transportation equipment) necessary for resilient emergency response; and ensure the infrastructure and equipment is adequately sheltered.
2. Pre-establish inventory of systems and components that may have an alternate use during emergencies (e.g. electrical systems, water-supply systems including fire pumps).
3. Ensure consideration is given to events that unfold over an extended time period – how will transitions between response teams be managed? – How will the basic living requirements (e.g. housing, food, clothing) be met?
4. Involve off-site emergency response capability in exercises to ensure lines of communication are effective and overall emergency response will be effective.

Research needs:

- How should updated risk assumptions (event frequency and consequence) drive changes to the emergency response infrastructure?
- Resilient procedure use: Can resilient procedure use, i.e. adapting existing procedures to unanticipated situations, provide an approach to smoothing the transition between a rule-based approach to a knowledge-based approach? Does there need to be a new approach to procedures? Do procedures need to reflect cultural differences, and can anything be learned from procedure use in different cultures?

APPENDICES

A. BREAKOUT DISCUSSIONS

Stress and cognition
(Session 2, Topic 1)

The group discussed the impact of stress on cognition and further on human performance in the context of beyond design accidents. Different very powerful stressors were identified such as

- emotional burden (due to threats),
- effects of surprise (consequences like freeze or overacting),
- sacrifice decisions,
- loss of control and information, and
- mental fatigue.

Different measures were taken into account to reduce stress impact. Participants concluded that it is important:

- to provide strategies of mental load control (guided by accepted models of cognition), and
- to consider and to be prepared for challenges like mental fatigue, reduced situational awareness (e.g. due to degraded amount of information), reduced cognitive capabilities (memory, search for explanation and action pattern, prediction of event development) and handling of interruptions (to wait).

Stress reduces flexibility. People tend to prefer well known explanation and decision patterns. It was proposed that a new kind of human factors engineering is needed to keep people flexible in grave emergencies. The following key factors were identified:

- Organisational preparedness shall include improvisation capabilities. In order to be flexible during emergencies it is also necessary to be flexible in normal situations. This notion challenges the current safety paradigm. How does a compliance culture (e.g. strictly follow the procedures) allow for the development of flexible response?
- It is important to have external people like stress managers on site, e.g. monitoring cognitive performance of emergency response team.
- Organisation shall be prepared for “mental fatigue” (e.g. back-up staff), problem solving difficulties (e.g. time limit when crew “stuck”) and reduced memory capabilities (e.g. provision of checklists and automation help to overcome this).
- People develop different behaviour during emergency situations. Training measures especially for leadership roles shall take that in consideration.
- Leadership and organisational structure will need to evolve during an event. A resilient organisation shall recognize this ability to evolve.

The group identified the following knowledge gaps:

- Stress research has remained an individual topic, it has not yet been integrated into cognitive psychology yet, this is a gap.

- Distributed/embodied cognition is not reflected in research models. When you are able to be in touch with other people (connectedness) you may be more capable of dealing with stress.
- Importance of person/person interactions for reducing stress
- The fundamental related question would appear to be "Can the ability to manage stress be developed in individuals independent of or in addition to expertise?"
- Relationship between compliance and resilience
  - Compliance is not compatible with resilience, but it is not as simple as this. We might not be as good as we could be in emergency situations.
  - Do we understand and use knowledge of metacognition? At the level of organisation and society there is a tension when suddenly operators are asked to be non-compliant in emergency situations.
- Impact of sacrifice decisions, non-compliance and legal responsibility.

Training and exercise
(Session 2, Topic 2)

The group observed a different international understanding of the terms "exercise" and "training". In order to be prepared for beyond design basis accidents the training should cover areas such as

- decision making,
- interaction between different organisations,
- communication and effective behaviour,
- leadership, and
- team behaviour.

The discussion of those areas revealed the following key factors of severe accident training and exercise:

- shift of decision making authority
- use of support tools (e.g. charts)
- handling of uncertainty and resilient (creative) use of procedures (including transition between the two approaches) as new training/exercise objectives
- learning from exercises by detailed debriefing sessions
- changing selection and qualification requirements should be considered. Managers (e.g. plant management) should have the capability to cope with stress.
- Due to limited available resources frequency and effectiveness of exercises and training should be evaluated. This includes use of different training and exercise locations like the control room, simulator and outside in the field.
- Training and exercise scenarios should be as realistic as possible (e.g. including dynamic aspects or problems with contradictory information).
- The limits of "realistic" training and exercise should be considered. In order to simulate emotional burden and threats ethical limits have to be accepted. To avoid "loss of trust in the system" effects a trade-off between illusion and trust should be found and be reflected within the debriefing sessions.

In view of those key elements the group agreed upon several existing knowledge gaps:

- Stress management and impact on cognition – To what extent it is justifiable from an ethical point of view to make exercises as realistic as possible, e.g. incorporate emotional stress in trainings and exercises.

- Learning from exercises – how can they be useful for the plant as well as proof of performance. How can necessary changes be implemented? Should limits of the exercises be explained in the debriefing? Can training to failure undermine human performance and learning?
- How to integrate the approach of a resilient organisation into simulator training programs effectively? How and should existing simulators be used to train the unexpected? Are charts good enough for exercises? Are we simulating the right things? Are there ethical issues?
- Should field / local tasks in harsh environments be simulated (train with negative performance shaping factors)?
- Can severe accident training be integrated with existing training because of time limitations / burden on operators? What about frequency of training and effectiveness?
- Transition from procedures to symptom based approach should be further investigated (need to understand it; manage it; organise for it).
- How to ensure that exercise scenarios are credible and challenging for the emergency response organisation (e.g. long-term accident scenario). Is it instructive to provoke failure when designing an exercise?

General organisational aspects
(Session 3, Topic 1)

Participants started the breakout session by discussing the organisational goals and the detailed content of the term "managing the unexpected". That leaded to one of the key issues, the question whether and how compliance and resilience design principles can be combined.

Up to now emergency concepts are organized like military units, very strict and defined. Resilience is a totally new concept for nuclear power plants. That concept includes:

- capability to improvise within the organisation,
- use of different (redundant) teams working on the same problem but with different points of view (could compensate decreasing problem solving capabilities but what happens when one team is more compliant than the other?),
- provision of decision autonomy as it is in a firefighter organisation during an emergency (distributed decision making versus centralized decision making among different groups, individuals, units and the question how to coordinate that within an organisation),
- continuously monitoring the current state of operation in order to change strategies and measures (e.g. from preventive to mitigation measures). That might be supported by indicators (see below),
- to allocate responsibility to sub-teams (to what extent?) and
- integration of "informal" organisational structures.

It was suggested that it is not possible to be compliant and resilient at the same time. Participants stated that it is necessary to go "outside" to know what resilience is in detail and how it can be transformed to nuclear organisations (e.g. connecting points between compliance and resilience principles). In order to improve organisational performance it is crucial to know enough about the "informal" organisation structure:

- There exist informal organisation structures with different competencies especially during an emergency situation. Such differences could have big impacts because the management often doesn't know these informal organisation structures. Management should take these.
- Informal organisational structures make organisations resilient because they can be described as an enrichment of work-as-imagined.

- The organisation has to have awareness about informal practices at the sharp end, because in every organisation informal practices will exist.
- Network analysis would be helpful to understand the flow of communication in an organisation and the gap between the predicted flow and the real flow of information.

Further it is necessary to develop indicators that measure resilience capabilities and the erosion of these capabilities or to find leading indicators (indicators before the emergency state). Up to now, resilience hasn't really been measured or operationalized. So what are leading and/or lagging indicators for a resilient organisation which are also able to detect an erosion of resilience capabilities? It may take some kind of crisis to figure out which indicators can be taken as a source to measure organisational resilience and the range/possibilities of resilience capabilities. The use of leading indicators for normal operations could be valuable to detect a possible erosion of resilience capabilities. Theses leading indicators could also be helpful finding out when to switch from the compliance mode to the emergency mode as mentioned (see above).

The participants concluded with the following recommendations:

- Know your experts and trust their decisions.
  - We have to try to rely on experts in the organisation who are really competent in their business. Therefore we have to know who is an expert for what.
- Keep questioning attitude.
  - Emergency strategies always have to be analysed and questioned and never be taken for granted.
- Develop an organisational structure to integrate redundancy (critical reflection of decisions).
  - Easier to make sense with other people.
  - Critical reflection of decisions is necessary.
  - Installation of a very reliable communication network.
- Know your alternative resources.
  - We have to know where alternative resources are and how we can make use of them.
- Create space for creative thinking.
  - Decision makers should have the opportunity to withdraw themselves for a short time and reflect about the situation without disturbances (e.g. for phone calls).

A number of knowledge gaps were identified:

- Search for the best organisational design to be resilient. It there one best organisational design?
- Transition issues between normal and emergency organisation.
- Tradeoff between compliance vs. resilience.
- Measurement of organisational resilience (leading/lagging indicators).
- Impact of informal organisation and its effect on resilience, especially in severe accident conditions.
- How do regulators assess capabilities for resilience?

Leadership, management, cultural aspects
(Session 3, Topic 2)

The participants discussed the following issues:

- distribution of leadership in the hierarchy,
- degree of adaptation in relation to leadership in order to be resilient,

- leadership - manage the coordination (stay away from micromanagement),
- judgment where to be at the right time,
- prepare to take turns to be the "top" manager,
- sacrifice decisions – ethical considerations,
- training specific leadership skills for critical situations,
- monitoring role for the leader, and
- cultivating a culture which allows for leadership feedback.

Many key factors impacting leadership and management were identified during the discussion:

- Military upstream – downstream principle
  - In military you train for both the upstream and downstream hierarchy level in order to fulfil their task in case they get wounded or killed. Military educates leadership although it is difficult.
- Provision of more realistic preparation
  - A nuclear operator/engineer explains that they prepare many procedures and tools for emergency situations, but they do not train for the unknown and he now asks the psychologists/sociologists to overcome this barrier. They need a result which they can apply and understand, not just theories. Is the knowledge from military applicable to the nuclear field?
- Limits of military command and control
  - Military command and control is not always effective when it comes to unexpected situations though.
- Role of informal leadership
  - Leadership changes when it comes to emergency situations.
- Leaders need someone for reflection.
  - They are usually very alone with their thoughts. Assistance is needed (and provided in military and firefighting).
- Challenging a leader's opinion
  - In some cultures it is very difficult to challenge a leader's opinion and different professional cultures should be taken into account.
- Collective versus individual thinking; dialogues are changing perspectives.
- Reliability versus resilience
  - A participant stated that reliability is much more important than resilience as in Fukushima was a problem of reliability. They have a strong concept of reliability; resilience can be brought in as long as it won't disturb reliability. The first goal of the nuclear industry is to avoid accidents, so that is why there is a large emphasis on reliability. Further it was stated that the world is more complex, reliability is not enough, we need to think beyond. What will we do if all our safety concepts fail? It's a question of whether Fukushima really is a question of resilience or an extraordinary event. We need to take into account that another accident will happen and we need to be more resilient.
- Professionalism and engagement
  - Engagement could be a threat for people's health while professionalism can protect people from this. The connection to leadership is for leaders to monitor people's engagement. Can this really work in all cultures?
- Sense making process
  - At the control room level people are probably very much trained in sense making. They check before they act. In the nuclear industry you have time to check and find a strategy. This belief of having time could be dangerous and should be revised.

- Leadership - followership principle
  - Leadership depends on followership; good leadership is made by followership.

The group recommended future work in the following areas:

- Better understand the relation between sense making and leadership (e.g. "how the story is created" at all levels with all stakeholders
- Leader's role to follow and adapt to the team and the relationship between leadership and followership
- Leader's role in managing the "outside" context e.g. media, politicians, local governments
- Develop guidance and training on how to alternate the "top" management role during critical situations

Many knowledge gaps were identified which need further investigation:

- Informal leadership role in critical situations
- How do we deal with cultural (national, professional) differences ability to flexibility/resilience?
- Can experiences from other sectors be utilized in nuclear and how useful is it?
- Engagement vs professional.
- Sense making role related to leadership
- What guidance is available for leadership in critical situations?
- Sacrifice decisions – ethical context.
- Leadership capabilities to optimize adaption in critical situations including cultivating a sound culture for leadership feedback and monitoring.

Comparing existing strategies for emergency preparedness, methodology and tools (Session 4, Topic 1)

Participants emphasized that infrastructures should be sufficiently flexible and specifically protected in order to support necessary resilient response of organisations facing a nuclear accident with extreme conditions, however different solutions were are proposed. The following measures were mentioned:

- protection by distance (requirement: ability to use the outside equipment within 72 hours)
- protection by bunkering (ability to withstand big impacts, identify resources which will probably survive)
- provision of resources for resilient responds and not for typical events
- provision of strategies for instruction and guidance of external staff (e.g. specific procedures including photo documentation)
- provision of a strategy to independently cope for a short-term period (e.g. "autonomy" conception, plant can be stabilized for a couple of hours without external assistance). In the course of a severe accident many dramatic changes take place in the first hours. After some days the situation becomes more stable in a sense that changes can be anticipated better while the main stress situation at this time may be the radiation. So the question here is, if we should give external entities more time to organize a response.
- Further development of defence in depth conception. That includes e.g.
  - Learning from Fukushima and "outside nuclear" accidents.
  - Review of basic assumptions on the frequency of the events and on the amount of impact is necessary (it is a permanent process to evaluate. Reconsider traditional ways to design emergency preparedness).

- Acknowledge the problem "limited resources". Everybody is looking for beyond design basis measures which might exceed available resources. Take advantage from improving "conventional" reactor safety measures (e, g. implementation of firefighting pumps for emergency feed water supply, measures to reduce hydrogen and to prevent containment over-pressurization by venting system).

Participants concluded with a number of practical recommendations:

- Provide procedures which can be used by external staff.
- Strategy for a long-term event.
- Autonomy conception.
- Respect defence in depth (Implement measures after core melt down).
- Take into account necessary organisational changes.
- Reconsider traditional ways to design emergency preparedness.

Some knowledge gaps were identified which needs further research:

- New assumptions about impact (multiple,..?).
- Review of basic assumptions on the frequency of events and of the amount of impact is necessary.

Procedure usage and design
(Session 4, Topic 2)

The group discussed the following issues relevant to evaluate and improve severe accident procedures:

- Balance between stability and flexibility, level of guidance.
- Realistic expectations concerning computerized procedures.
- Knowledge transfer to younger operators.
- Management of the amount of procedure, usability of the procedure system.
- Individual differences, could procedures accommodate better, including experience of operators.
- What is needed to get crews to use procedures in an interpretative view (identify anomalies).
  - Training?
  - Procedure design?
  - Team culture, team dynamics?
- Taking national and organisational and team cultures into account.
- Different types of procedures e.g. text, flowchart.
  - Some procedures may be better used in a confirmative way.
- How to manage the transition to SAM (Severe Accident Management) guidelines.
- How to design support systems for procedure usage.
- Keeping an overview while using procedures.
- How to facilitate collaboration while using procedure.

It was emphasized that practical procedure use is related on sense making. Computerized procedures could provide redundancy and diversity. Resilient use of procedures might improve reliability, but what could be the process of overwriting a procedure (not one single decision should kill several analysis, use a more systemic view)? The level of flexibility in using procedures is impacting the level of trust in the procedures (how to deviate and elaborate a strategy?). The knowledge transfer to the procedures should be improved (documentation of the "knowing-why" and stronger link between training and new procedures). For whom you have a procedure depends on the culture, the ages, not everybody interprets them in the same way, depending on experience.

Participants concluded with the following practical recommendations:

- Development of new procedure "philosophy".
- Shift technical advisor (as an independent resource, monitoring on a meta level).
- Apply human factors expertise in procedure design, also training > systemic approach in procedure design.
- Maintain and explicate design rationale and design basis.
- Acknowledge that information may need to be presented in different ways according to the function and purpose of procedure.
- Be careful with over-procedurelization.

A number of knowledge gaps were identified which need further research:

- What knowledge can we leverage from other industries (oil industry, aviation)? > Learning from other domains.
- Direct data about practical procedure use.
- What is the process of deviating from procedure?
- Trust and confidence in procedures.
- Interaction of reliability and resilience.
- Comparing the procedure use in practice in different cultures.
- What is adaption in procedure use and how to change to knowledge-based activity while transferring to severe accident management guidelines?
- What is the new procedure philosophy?
- What new ad-hoc organisational resources could help to increase resilience procedure-based activity?

B. WORKSHOP TIME SCHEDULE

	Monday, 24th Feb	Tuesday, 25th Feb	Wednesday, 26th Feb	
08:30		Session 2 Human (8:30-9:00)	Session 4 Infrastructure (8:30-10:30)	08:30
09:00		Break out 2 Human (9:00-11:30)		09:00
09:30				09:30
10:00	Coffee (10:00-10:30)			10:00
10:30	Welcome, Agenda (10:30-11:00)	Coffee (10:30-11:00)	Coffee (10:30-11:00)	10:30
11:00	Session 1 Intro Part 1 (11:00-13:30)		Break out 4 Infrastructure (11:00-13:00)	11:00
11:30		Lunch (11:30-12:30)		11:30
12:00				12:00
12:30		Session 3 Organisation (12:30-15:30)		12:30
13:00			Lunch (13:00-14:00)	13:00
13:30	Lunch (13:30-14:30)			13:30
14:00			Wrap-up (14:00-15:00)	14:00
14:30	Session 1 Intro Part 2 (14:30-16:00)			14:30
15:00			End	15:00
15:30		Coffee (15:30-16:00)		15:30
16:00	Coffee (16:00-16:30)	Break out 3 Organisation (16:00-18:00)		16:00
16:30	Session 2 Human (16:30-18:00)			16:30
17:00				17:00
17:30				17:30
18:00	End	End		18:00
18:30				18:30
19:00		Vindonissa Museum Guided tour & buffet (19:00-21:30)		19:00
19:30				19:30
20:00				20:00
20:30				20:30
21:00				21:00

C. LIST OF PARTICIPANTS

Belgium

Bernard Benoît
Bel V
Rue Walcourt 148
B-1070 Brussels

Tel: +32 (0) 2 52 80 354
EM: benoit.bernard@belv.be

Canada

Alice Salway
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
1601 Telesat Court
Ottawa, ON K1P 5S9

Tel: +1 613 991 3271
EM: Alice.Salway@cnsc-ccsn.gc.ca

Finland

Leena Norros
VTT Technical Research Centre of Finnland
Vuorimiehentie 3,
PO Box 1000
02044 VTT

Tel: +358 (0) 9 759 88 697
EM: Leena.Norros@vtt.fi

Paula Savioja
VTT Technical Research Centre of Finnland
Vuorimiehentie 3
PO Box 1000
02044 VTT

Tel: +358 (0) 40 5000847
EM: paula.savioja@vtt.fi

France

Bertrand Domeneghetti
Direction générale de la sécurité et de la gestion des crises
87-95 Quai du Docteur Dervaux
F-92600 Asnières-sur-Seine

Tel: +33 (0) 1 56 04 75 37
EM: bertrand.domeneghetti@interien.gow.fr

Geneviève Filippi
R&D EDF
1 av du General de Gaulle
F-92140 Clamart

Tel : +33 (0) 1 47 65 43 90
EM : genevieve.filippi@edf.fr

Jean Paries
DEDALE
15 place de la Nation
F-75011 Paris

Tel : +33 1 58 39 30 91
EM : jparies@dedale.net

Daniel Tasset
IRSN
B.P. 17
F-92262 Fontenay-aux-Roses Cedex
Tel : +33 (0) 1 58 35 90 09
EM : daniel.taset@irsn.fr

Germany

Mario Hellmich
Bundesamt für Strahlenschutz
Fachbereich Sicherheit in der Kerntechnik
Willy-Brandt-Str. 5
38226 Salzgitter
Tel: +49 (0) 30 18333 1033
EM: mhellmich@bfs.de

Wolfgang Preischl
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)mbH
Boltzmannstraße 14
85748 Garching
Tel: +49 (0) 89 32004-481
EM: Wolfgang.Preischl@grs.de

Thomas Putzek
GfS Gesellschaft für Simulatorschulung mbH
Deilbachtal 173
45257 Essen (Kupferdreh)
Tel: +49 (0) 201 4862 233
EM: t.putzek@KSG-GfS.de

Mandy Richter
ESN Sicherheit und Zertifizierung GmbH
Lise-Meitner-Straße 25-29
24223 Schwentinental
Tel: +49 (0) 4307 821 193
EM: richter@esn.de

Oliver Wilhelm
EnBW AG, NPP Philippsburg
Rheinschanzinsel
76667 Philippsburg
Tel: +49 (0) 7256 95 139 66
EM: ol.wilhelm@kk.enbw.com

Japan

Ryuji Kubota
Japan Nuclear Energy Safety Organisation
Toranomon, Minato-ku
Tokkyo 105-0001
Toranomon Tower Office, 4-1-28
Tel: +81 (3) 4511 1784
EM: kubota-ryuji@jnes.go.jp

Korea

Wondea Jung
Integrated Safety Assessment Dept.
150 Duckjin-dong
Yuseong, Daejeon
Tel: +82 42 868-8296
EM: wdjung@kaeri.re.kr

The Netherlands

Margreet Steenhuisen
Inspectie Leefomgeving en Transport (ILT)
Koningskade 4
2596AA Den Haag
Tel: +31 62 290 99 00
EM: margreetsteenhuisen@ilent.nl

Norway

Michael Hildebrandt
Institute for Energy Technology
PO Box 173
1751 Halden
Tel: +47 (0) 4 137 49 82
EM: hilde@hrp.no

Sweden

Axelsson Lars
Swedish Radiation Safety Authority (SSM)
Solna strandväg 96
SE-171 16 Stockholm
Tel: +46 (0) 8 799 43 30
EM: lars.axelsson@ssm.se

Alf Ingesson Thoor
Major. Pilot Swedish Air Force
Aviation Psychologist
Spec. Crises and stress management
Sågmästargatan 11
SE-546 31 Karlsborg
Tel: +46 (0) 706517874
EM: Affe.int@gmail.com

Switzerland

Thomas Bichsel
NPP Gösgen-Däniken AG
Postfach
CH-4658 Däniken
Tel: +41 (0) 62 288 27 61
EM: tbichsel@kkg.ch

Wolfgang Hoesel
NPP Leibstadt AG
CH-5325 Leibstadt
Tel: +41 (0) 56 267 8523
EM: Wolfgang.hoesel@kkl.ch

Claudia Humbel
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8677
EM: claudia.humbel@ensi.ch

Holger Knissel
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8562
EM: holger.knissel@ensi.ch

Andrea Lohse
Federal Department of Defence Civil Protection and Sport
Bettlistr. 16
CH-8600 Dübendorf
Tel: +41 (0) 79 568 7627
EM: Andrea.Lohse@vtg.admin.ch

Friedrich Meynen
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8556
EM: friedrich.meynen@ensi.ch

Philip Noser
Federal Department of Defence Civil Protection and Sport
Bettlistr. 16,
CH-8600 Dübendorf
Tel: +41 (0) 79 592 34 82
EM: Philip.noser@vtg.admin.ch

Larissa Peloli
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8609
EM: larissa.peloli@ensi.ch

Cornelia Ryser
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8536
EM: cornelia.ryser@ensi.ch

Toni Waefler
University of Applied Sciences and Arts Northwestern Switzerland, School of Applied Psychology
Riggenbachstrasse 16
CH-4600 Olten
Tel: +41 (0) 62 957 24 61
EM: toni.waefler@fhnw.ch

Hans Wanner
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Tel: +41 (0) 56 460 8568
EM: hans.wanner@ensi.ch

United Kingdom

Berman Jonathan
Greenstreet Berman Ltd
Fulcrum House
5 Southern Court, South Street,
Reading RG1 4QS
Tel: +44 (0) 118 938 7703
EM: jon.berman@greenstreet.co.uk

Gary Munlay
Office for Nuclear Regulation
Desk 31, 4S.1 Redgrave Court,
Merton Road, Bootle L20 7HS
Tel: +44 (0) 151 9515717
EM: Gary.munley@hse.gsi.gov.uk

United States

David Desaulniers
Nuclear Regulatory Commission
MS T-7D24
Washington, DC 20555
Tel: +1 301 415 5918
EM: David.Desaulniers@nrc.gov

Kathleen Sutcliffe
Ross School of Business
University of Michigan
701 Tappan SI
Ann Arbor , MI 48109-1234
Tel: +1 734 164 2312
EM: ksutclif@umich.edu

International organisations

International Atomic Energy Agency

Monica Haage
IAEA
PO Box 100
A-1400 Wien

Tel: +43 (0) 1 26 00 22551
EM: m.haage@iaea.org

OECD Nuclear Energy Agency

Andrew White
Nuclear Safety Division
OECD Nuclear Energy Agency
Le Seine Saint-Germain
12 boulevard des Iles
F-92130 Issy-les-Moulineaux

Tel: +33 (0) 1 45 24 10 53
EM: andrew.white@oecd.org