“The Fukushima Daiichi Accident”
Technical Volume 2.6

A Systemic Analysis of Human and Organizational Factors at the Fukushima Daiichi Accident

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Monica Haage, IAEA
“The Fukushima Daiichi Accident”

- Report by the IAEA Director General
- Five technical volumes
- The result of extensive international collaborative effort involving 5 working groups with about 180 experts from 42 Member States
FOREWORD - Yukiya Amano, IAEA Director General

"This report presents an assessment of the causes and consequences of the accident at the Fukushima Daiichi nuclear power plant in Japan, which began on 11 March 2011. Caused by a huge tsunami that followed a massive earthquake, it was the worst accident at a nuclear power plant since the Chernobyl disaster in 1986.

The report considers human, organizational and technical factors, and aims to provide an understanding of what happened, and why, so that the necessary lessons learned can be acted upon by governments, regulators and nuclear power plant operators throughout the world. Measures taken in response to the accident, both in Japan and internationally, are also examined…"

"There can be no grounds for complacency about nuclear safety in any country. Some of the factors that contributed to the Fukushima Daiichi accident were not unique to Japan. Continuous questioning and openness to learning from experience are key to safety culture and are essential for everyone involved in nuclear power. Safety must always come first.”
Human and Organizational Factors Analysis

The HOF team of 11 experts:
• Kathleen Heppell-Masys, Lead, CNSC
• Monica Haage, Coordinator, IAEA
• Amanda Donges, INPO
• Hanna Kuivalainen, STUK
• Sonja Haber, IAEA
• Cornelia Ryser, ENSI
• Birgitte Skarbø, IAEA
• Per Chaikiat, SSM
• Luigi Macchi, Dedale (VTT)
• Kunito Susumu, TEPCO
• Takafumi Ihara, TEPCO
Objective of the HOF team:

As a part of the overall IAEA Fukushima Report, address how human and organizational factors and safety culture contributed to the event in a comprehensive manner to address the “whys” of the event

- Aim to perform a systemic analysis of the accident capturing the relationship and synergies between the actors involved
- Develop lessons learned
The human and organizational analysis was conducted in accordance with social and behavioural science procedures, which comprise four equally important elements:

- Recognized methodology;
- Unbiased data;
- Scientifically recognized theory;
- Knowledgeable experts contributing with diversified competences.
HOF Team Methodology

Systemic Analysis Data Collection:

• Approx. 30 reports and other written sources identified by HOF team
• 10 main reports selected for extracting facts relevant to HOF and Safety Culture
  • Created HOF Cumulative Fact Database
• Collecting information from experts contributing to Report to determine HOF and Safety Culture factors contributing to the event sequence
• Collecting information from various other sources
  • Interview with Professor Hatamura, Former Chairperson of Investigation Committee on the Accident at the Fukushima Nuclear Power Stations
  • Reports from CS in Japan
Systemic Analysis Data Analysis:

- Extracted facts on HOF and Safety Culture from 10 selected accident reports
- All facts were assigned to a category and one or more attributes
  - The HOF team jointly developed a list of categories and attributes
- All facts were inserted to a Cumulative Fact Database in a manner that allowed for sorting for category and attribute
Example of Cumulative Database

<table>
<thead>
<tr>
<th>Reading List</th>
<th>Fact Code</th>
<th>Fact</th>
<th>Category</th>
<th>Attribute/Qualifier</th>
<th>Description</th>
<th>Timeline (B,D,A)</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>6a</td>
<td>Icf21</td>
<td>To the question, “Don’t you think it was possible to propose the development of AM based on seismic PSA?” He (Kondo, chairman of the Special Committee on Safety Goals by NSC) answered, “We could have made such a decision. The question was when to make that decision. With regard to seismic PSA, we intended to start it on the occasion of the periodical safety review (PSR). Although the first-round PSR reviewed only internal event PSA, we had no choice about that, I intended to include external event PSA in the second-round PSR 10 years later. (p. 365)</td>
<td>Regulatory culture</td>
<td>Regulatory practice</td>
<td>B</td>
<td>NSC, Government</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>If4</td>
<td>“moreover, those additional protective measures were not reviewed and approved by the regulatory authority” (p. 13 and 45)</td>
<td>Regulatory Framework</td>
<td>Roles &amp; Responsibilities</td>
<td>B</td>
<td>Regulator</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T102</td>
<td>“The legally mandated METI order to continue seawater injection was issued at 10:30 on March 15. This information was shared via teleconferencing at 10:37. The document containing the METI order stated that “reactor injection is to be performed as early as possible, with D/W venting performed as needed.”” (p. 219)</td>
<td>Roles &amp; Responsibilities</td>
<td>Organizational Interfaces</td>
<td>D</td>
<td>IF, TEPCO, METI</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T72</td>
<td>“The station and head office response HQs were notified that the TEPCO government attaché decision was “the Prime Minister has not approved seawater injection” at 19:25. After deliberation between the head office and station, it was decided that seawater injection would be halted.” (p. 183)</td>
<td>Roles &amp; Responsibilities</td>
<td>Organizational Structure (Hierarchy)</td>
<td>D</td>
<td>IF, TEPCO, PM</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T74</td>
<td>“However, due to the decision by the Site Superintendent that continuing reactor injection was vital in preventing accident progression, seawater injection was continued in actuality.” (p. 184)</td>
<td>Roles &amp; Responsibilities</td>
<td>Changing the rules of the game</td>
<td>D</td>
<td>IF</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>D5-91</td>
<td>“We heard a big impact noise between 6:00 and 6:10. We will make the necessary arrangements and move our Emergency Response office to the Fukushima Daini Nuclear Power Plant to ensure the safety of our staff.” [139] On the other hand, the following was the press released published to report the status as of 13:00. “Around 6:00, we heard a big noise around the suppression chamber and its pressure rapidly lowered. We have been injecting seawater into the reactor at full throttle and have begun to temporarily move our contractors and employees not directly involved in this operation to a safe location.”</td>
<td>Constrained Thinking and Actions</td>
<td>Control mode</td>
<td>Delaying release of information to the public</td>
<td>D</td>
<td>TEPCO</td>
</tr>
</tbody>
</table>

4900 facts classified into 26 categories, 96 attributes
Example of fact extraction & categorization:

The department responsible for safety design believed that rational explanations could be given for facility measures requiring huge expenditure unless reliable PRA methods were perfected and it would be difficult to obtain consent within the company.

TEPCO March 2013 report, Pg.13

Category: Decision-Making
Attributes: Business Impact, Methodology, Monetary, Safety Culture
<table>
<thead>
<tr>
<th>Categories</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident Management</td>
<td>Accident Management</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Accountability</td>
</tr>
<tr>
<td>Communications</td>
<td>Adaptation</td>
</tr>
<tr>
<td>Competence</td>
<td>Expertise</td>
</tr>
<tr>
<td>Constrained thinking and actions/not thinking out of boundaries</td>
<td>Emergency Preparedness</td>
</tr>
<tr>
<td>Control of Information</td>
<td>Adhered to procedures or requirements</td>
</tr>
<tr>
<td>Decision-making</td>
<td>Assumption of human error</td>
</tr>
<tr>
<td>Design</td>
<td>Availability of Information</td>
</tr>
<tr>
<td>Emergency Preparedness</td>
<td>Business Impact</td>
</tr>
<tr>
<td>Emergency Response</td>
<td>Changing the rules of the game</td>
</tr>
<tr>
<td>Human performance</td>
<td>Fear of the Unknown</td>
</tr>
<tr>
<td>Initiative</td>
<td>Communication following core meltdown</td>
</tr>
<tr>
<td>Legal Framework</td>
<td>Design</td>
</tr>
<tr>
<td>Management Systems</td>
<td>Communications external</td>
</tr>
<tr>
<td>Nuclear Infrastructure</td>
<td>Communications internal</td>
</tr>
<tr>
<td>Regulatory Culture</td>
<td>External Support</td>
</tr>
<tr>
<td>Regulatory Framework</td>
<td>Formality</td>
</tr>
<tr>
<td>Risk management</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Roles &amp; Responsibilities</td>
<td>Configuration Documentation</td>
</tr>
<tr>
<td>Situational awareness</td>
<td>External</td>
</tr>
<tr>
<td>Staffing</td>
<td>Conflicting priorities</td>
</tr>
<tr>
<td>Taking Ownership</td>
<td>Facility Layout</td>
</tr>
<tr>
<td>Training</td>
<td>Coordination of dissemination of information</td>
</tr>
<tr>
<td>Transparent Culture</td>
<td>Coordination with Others</td>
</tr>
<tr>
<td>Unavailability of Information</td>
<td>Decision-making</td>
</tr>
<tr>
<td>Work Environment</td>
<td>…and 70 more</td>
</tr>
</tbody>
</table>
- Sorted facts by category or attribute for the team to review them together

<table>
<thead>
<tr>
<th>Reading List Number</th>
<th>Fact Code</th>
<th>Fact Code</th>
<th>Category</th>
<th>Attribute/Qualifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Ad15</td>
<td>Ad15</td>
<td>Decision-Making</td>
<td>Provided Margin</td>
</tr>
<tr>
<td>7</td>
<td>Ad27</td>
<td>Ad27</td>
<td>Decision-Making</td>
<td>Adhered to Procedures or Requirements</td>
</tr>
<tr>
<td>3</td>
<td>D102</td>
<td>D102</td>
<td>Decision-Making</td>
<td>Actions</td>
</tr>
<tr>
<td>3</td>
<td>D103</td>
<td>D103</td>
<td>Decision-Making</td>
<td>Talent Management</td>
</tr>
<tr>
<td>3</td>
<td>D140</td>
<td>D140</td>
<td>Decision-Making</td>
<td>Failed to take actions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<tr>
<td>7</td>
<td>Ad15</td>
<td>Ad15</td>
<td>Decision-Making</td>
<td>Provided Margin</td>
</tr>
<tr>
<td>7</td>
<td>Ad27</td>
<td>Ad27</td>
<td>Decision-Making</td>
<td>Adhered to Procedures or Requirements</td>
</tr>
<tr>
<td>3</td>
<td>D102</td>
<td>D102</td>
<td>Decision-Making</td>
<td>Actions</td>
</tr>
<tr>
<td>3</td>
<td>D103</td>
<td>D103</td>
<td>Decision-Making</td>
<td>Talent Management</td>
</tr>
<tr>
<td>3</td>
<td>D140</td>
<td>D140</td>
<td>Decision-Making</td>
<td>Failed to take actions</td>
</tr>
</tbody>
</table>

Review of facts sorted by category “Decision-making”
Report Methodology (cont.)

- Sorted facts by category or attribute for the team to review
- Performed a two-fold mapping exercise identifying relationships, concepts and trends resulting in mini-themes and overarching themes
- Text on mini themes & overarching themes produced by team members based on the mapping exercises
- Reviewed by whole team and discussed during meetings
- Concluded by
  - Lessons learned
  - Identification of areas where further needed (Phase 2)
Analysis: Mapping exercises

- Performing a two-fold mapping exercise identifying relationships, concepts and trends resulting in mini-themes and overarching themes
Methodology - overview

Producing conclusions, lessons learned and identify areas for further research (Phase 2)

Text produced and reviewed

Analysis: information is systematically grouped and overarching themes are identified.

Human and organizational factors and safety culture mini themes

Human and organizational factors and safety culture facts

Collection of data on human and organizational factors and safety culture from Fukushima reports

Collection of data on human and organizational factors and safety culture from other WG experts

Collection of data on human and organizational factors and safety culture from other sources
Comments from WG2 co-chair

- Challenge to communicate “soft aspects” to a technical audience

- Comments from the co-chairs of WG 2 (covering Safety Assessment) of the Fukushima Report:

  "Results are aligned with the results from the rest of chapter 2 and provided further explanations to the current understanding. The methodology used is sound and its validate the rest of the working groups conclusions"
The hindsight bias
Distancing through differencing

• An accident provides an opportunity to learn, not only for the organizations involved in the accident, but also for the other organizations within and outside the industry concerned. After an accident a ‘learning window’ opens where it is possible to ask questions that are usually not asked during non-accident times.

• However, learning after an accident is far from easy. One must not focus on just trying to learn the ‘obvious’, but must also capture more subtle, important lessons as they emerge over time.

• Learning after an accident is subject to barriers. One of these barriers is a mechanism called ‘distancing through differencing’, exemplified by the statement “this can’t happen here”. Such a response is likely to occur particularly in organizations that are distant enough from the ones directly involved in the accident; for example, operators and regulators in other countries. One example of this is the missed opportunity to address the operating experience gained from the 1999 flooding event at the Le Blayais NPP in France.
Observation:

Over time, the stakeholders of the Japanese nuclear industry developed a shared basic assumption that plants were safe

- Led stakeholders to believe that a nuclear accident would not happen;
- Thwarted their ability to anticipate, prevent and mitigate the consequences of the earthquake triggering the Fukushima Daiichi Accident;
Levels of culture

- Behaviour, Artefacts
- Shared Values, Norms
- Shared Basic Assumptions
Shared basic assumption across stakeholders

Licensee

Public/government

Regulatory Body

“We are safe”
Observation:
Over time, the stakeholders of the Japanese nuclear industry developed a shared basic assumption that plants were safe
- Led stakeholders to believe that a nuclear accident would not happen;
- Thwarted their ability to anticipate, prevent and mitigate the consequences of the earthquake triggering the Fukushima Daiichi Accident;

Lessons Learned:
The possibility of the unexpected needs to be integrated into the existing worldwide approach to nuclear safety – including considerations for emergency preparedness

Individuals and organizations need to consciously and continuously question their own basic assumption and their implications on actions that impact nuclear safety.
The boundaries of our basic assumptions

- **Known knowns**
  - E.g. that earthquakes and tsunamis occur
- **Known unknowns**
  - E.g. we know that we do not know when an earthquake will occur and how devastating it will be
- **Unknown unknowns**
  - E.g. combined effect of earthquake and tsunami on multiple units at nuclear power plants
- **Surprise**
  - Surprise occurring outside boundaries of one’s basic assumptions
Observation:
While the stakeholders involved in the accident at the Fukushima Daiichi NPP were aware of the possibility of the single safety issues related to the accident in advance they were not able to anticipate, prevent or successfully mitigate the outcome of the complex and dynamic combination of these issues within the sociotechnical system.

Lesson Learned:
• To proactively deal with the complexity of nuclear operations, the results of research on complex sociotechnical systems for safety need to be taken into account by all stakeholders involved.
• A systemic approach to safety needs to be taken in event and accident analysis, considering all stakeholders and their interactions over time.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Known knowns</th>
<th>Known unknowns</th>
<th>Unknown unknowns</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seismic event</strong></td>
<td>Design basis of the Fukushima Daiichi NPP and prediction of its design basis seismic performance</td>
<td>Response of the Fukushima Daiichi NPP to a seismic event exceeding its design margin</td>
<td>Outside the boundaries of the shared assumptions of main stakeholders</td>
</tr>
<tr>
<td><strong>Tsunami</strong></td>
<td>Tsunamis are a co-related event to seismic events.</td>
<td>The prediction of tsunami heights</td>
<td></td>
</tr>
<tr>
<td><strong>Loss of off-site power (LOOP)</strong></td>
<td>The Fukushima Daiichi NPP was designed for a loss of off-site power, with the expectation that the grid would be restored quickly.</td>
<td>The extent of grid damage and infrastructure disruption for a very large earthquake and tsunami</td>
<td></td>
</tr>
<tr>
<td><strong>SBO</strong></td>
<td>Should SBO occur, the DC (batteries) would last for about 4–6 hours. If AC was not restored in that time, core damage was to be expected.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Emergency Diesel Generators (EDGs)</strong></td>
<td>Expected to function on LOOP to provide AC power. Endurance based on diesel stock replenishment capability</td>
<td>Diesels can fail to start and duration of service may be unpredictable.</td>
<td></td>
</tr>
<tr>
<td><strong>Switchgear</strong></td>
<td>Interconnections allow cross feeding of power from one unit to its neighbour.</td>
<td>Availability of equipment and/or staff to effect interconnection in a severe accident</td>
<td></td>
</tr>
<tr>
<td><strong>Procedure for notification of a nuclear emergency</strong></td>
<td>After NPP Site Superintendent is notified or discovers the specific event defined in Article 10 (1) of the Nuclear Emergency Preparedness Act of Japan, he/she shall, within a targeted time frame of 15 minutes, simultaneously notify all relevant entities by fax.</td>
<td>Site superintendent perception of severity of event, communication infrastructure available.</td>
<td></td>
</tr>
<tr>
<td><strong>Staffing on site</strong></td>
<td>Minimum number of staff available on site at the beginning of an accident is known</td>
<td>Capability to relieve staff if severe condition persists over prolonged period in case of damage to outside infrastructure</td>
<td></td>
</tr>
<tr>
<td><strong>Capability of staff for accident response</strong></td>
<td>Formal competences of staff to respond to an anticipated type of accident is known (training, experience)</td>
<td>Psychological and physical condition and ability of staff to respond to an event under severe conditions in a given moment</td>
<td></td>
</tr>
<tr>
<td><strong>Etc.</strong></td>
<td>…</td>
<td>…</td>
<td>Combination of all elements above = Unknown unknown</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The systemic approach to safety – HTO

- Work to comprehend the whole systems of interplay between humans, technology and organization (HTO)
- As the whole system is far too complex for one individual to comprehend, an integrated approach is needed, which invites different competencies and thinking
- Understanding the dynamics of the HTO interactions helps us to evaluate their ability to produce safety outcomes more effectively
- A systemic approach to safety offers a complementary safety perspective to Defence in Depth
Examples of Human, Organizational and Technical Factors

Organizational Factors (OF):
- Vision and objectives
- Strategies
- Integrated Management System
- Continuous improvements
- Priorities
- Knowledge management
- Communication
- Contracting
- Work environment
- Culture
- etc

Technical Factors (TF):
- Existing technology
- Sciences
- Design
- PSA/DSA
- I/C
- Technical Specifications
- Quality of material
- Equipment
- etc

Human Factors (HF):
- Human capabilities
- Human constraints
- Perceived work environment
- Motivation
- Individuals understanding
- Emotions
- etc
Lessons Learned:

The regulatory body needs to acknowledge its role within the national nuclear system and the potential for its impact on the nuclear industry’s safety culture.

- RB has the challenging role of questioning the nuclear industry’s approach to safety → Needs a critical, profound self-reflecting and questioning ability.
- May include institutionalizing an ongoing dialogue within the organization and with other stakeholders on the regulatory body’s safety culture and its impact on nuclear safety.

Licensees, regulators and governments need to conduct a transparent and informed dialogue with the public on an ongoing basis. This may include explanation of the risks that the use of nuclear technology for energy production entails.
Systemic View of Interactions between Organizations

Governmental Ministries

Regulatory Body

Licensee

Media

Suppliers

Universities

Professional Associations

Standards Organizations

Lobby Groups

Competing Energy Providers

Interest Groups

Work Unions

Energy Markets

International Bodies

Technical Support Organizations

Vendors

Waste Management Organizations

IAEA
The bigger, bigger picture
The relation with safety culture: Self reinforcing dynamics

Strong safety culture

HTO – embraces the systemic interactions
Personal Reflection

Suprise that the critical issues where also identified often in the experts own working experience

”…I recognize this, a similair matter happen in…”

Not many people know what really happened, the have drawn conclusion on what has been communicated in media

Some experts tend to isolate the accident something that happened in Japan, we dont have the same situation here e.g. Tsumani, different, technology, national context

The human aspect of the accident is often forgotten. Example:

- **TABLE II–1. AFTERSHOCKS OF THE GREAT EAST JAPAN EARTHQUAKE (JAPAN METEOROLOGICAL AGENCY)**
- Number of aftershocks on 11 March 2011 – 180 >M 5.0; 38 >M 6.0; 3 >7.0
- Total aftershocks the first week 463 times > 5.0
<table>
<thead>
<tr>
<th>Seismic intensity</th>
<th>Human perception and reaction</th>
<th>Indoors situation</th>
<th>Outdoors situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Most people are startled. Felt by most people walking. Most people are awoken.</td>
<td>Hanging objects such as lamps swing significantly and dishes in cupboards rattle. Unstable ornaments may fall.</td>
<td>Electric wires swing significantly. Those driving vehicles may notice the tremor.</td>
</tr>
<tr>
<td>5 Lower</td>
<td>Many people are frightened and feel the need to hold onto something stable.</td>
<td>Hanging objects such as lamps swing violently, dishes in cupboards and items on bookshelves may fall. Many unstable ornaments fall. Unsecured furniture may move and unstable and unstable furniture may topple over.</td>
<td>In some cases, windows may break and fall. People notice electricity poles moving. Roads may sustain damage.</td>
</tr>
<tr>
<td>5 Upper</td>
<td>Many people find it hard to move, walking is difficult without holding onto something stable.</td>
<td>Dishes in cupboards and items on bookshelves are more likely to fall. TVs may fall from their stands, and unsecured furniture may topple over.</td>
<td>Windows may break and fall, unreinforced concrete-block walls may collapse, poorly installed vending machines may topple over, automobiles may stop due to the difficulty of continued movement.</td>
</tr>
<tr>
<td>6 Lower</td>
<td>It is difficult to remain standing.</td>
<td>Many unsecured furniture moves and may topple over. Doors may become wedged shut.</td>
<td>Wall tiles and windows may sustain damage and fall.</td>
</tr>
<tr>
<td>6 Upper</td>
<td>It is impossible to remain standing or move without crawling. People may be thrown through the air.</td>
<td>Most unsecured furniture moves, and it is more likely to topple over.</td>
<td>Wall tiles and windows are more likely to break and fall. Most unreinforced concrete-block walls collapse.</td>
</tr>
<tr>
<td>7</td>
<td>Most unsecured furniture moves and topples over, or may even be thrown through the air.</td>
<td>Wall tiles and windows are even more likely to break and fall. Reinforced concrete-block walls may collapse.</td>
<td>Wall tiles and windows are more likely to break and fall. Most unreinforced concrete-block walls collapse.</td>
</tr>
</tbody>
</table>
...Thank you for your attention
The Complex Perspective

Examples of external factors which influence the ongoing interactions between HF, OF and TF

- Societal context
- Political climate
- Culture
- Peoples understanding
- Generational shift
- Public opinion
- Media
- Implementation and reinforcement of Law – Regulations
- New management trends
- Financial climate
- International Standards
Over-confidence in the ability of the technical features of the plant can be problematic

Assumptions about the safety case need to be challenged by:
- the operating organizations
- the regulatory body and government

Regulatory oversight must be robust including:
- regulatory framework and legal powers
- independence

Over-confidence impact on organizational learning
- impact on decision making
- OPEX quality
Response Under Extreme Circumstances

Operators who directly responded in the early stages of the accident did so under extreme circumstance

Extremely adverse working environment both physically and psychologically

- anxiety and stress
- uncertainty about their family and home
- inadequate provisions for rest, sleep, hygiene, food and water
- tasks conducted in darkness while wearing personal protective equipment
Accident Management Provisions & Implementation

- Analytical support for accident management
- Procedures and guidelines for accident management
- Hardware provisions
  - plant status information
  - means for water injection etc.
- Organization and arrangement
  - training, exercises and drills
  - under extreme/degraded plant conditions
- Interfaces with off-site emergency arrangements
A complementary strategy to ensure flexibility within a system

- learning from successful normal operations
- paradigm shift away from the traditional approach
- understand strengths as well as vulnerabilities
- complexity, uncertainty, and unpredictability
- capitalize on behaviours and processes that resulted in positive outcomes
- better prepared to deal with the unexpected