Operators' Improvisation in Complex Technological Systems: The Last Resort to Averting an Assured Disaster

***Personal* Observations**

Najm Meshkati
Professor
Civil/Environmental Engineering
Industrial & Systems Engineering
International Relations
University of Southern California (USC)

Human and Organizational Aspects of Assuring Nuclear Safety
IAEA, Vienna, February 23, 2013

My life story…..

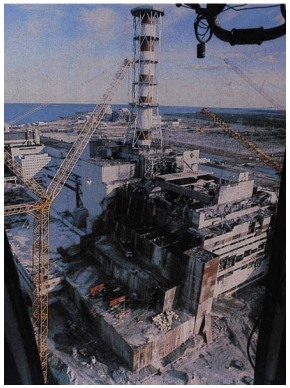
Three Mile Island

March 28, 1979

Bhopal

December 3, 1984

Chernobyl



April 26, 1986

BP Refinery

March 23, 2005

BP Deepwater Horizon

April 20, 2010

Fukushima

March 11, 2011

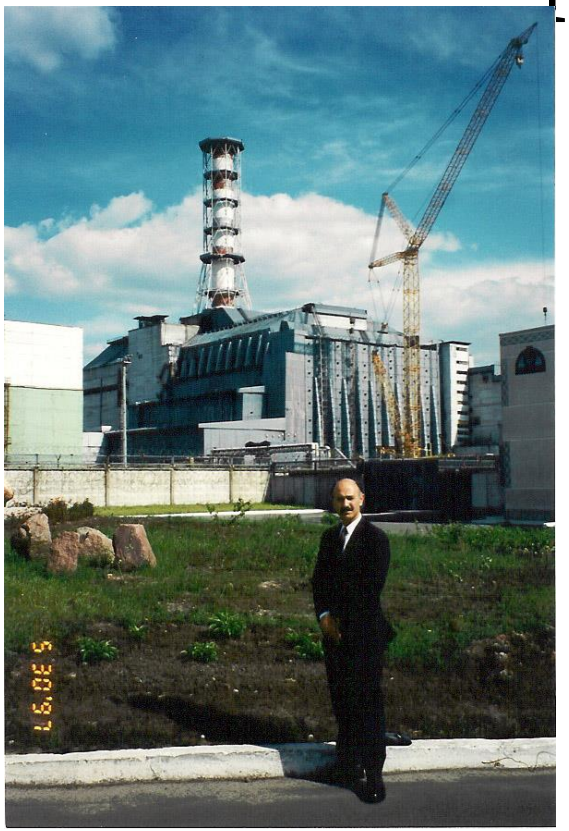
My story…

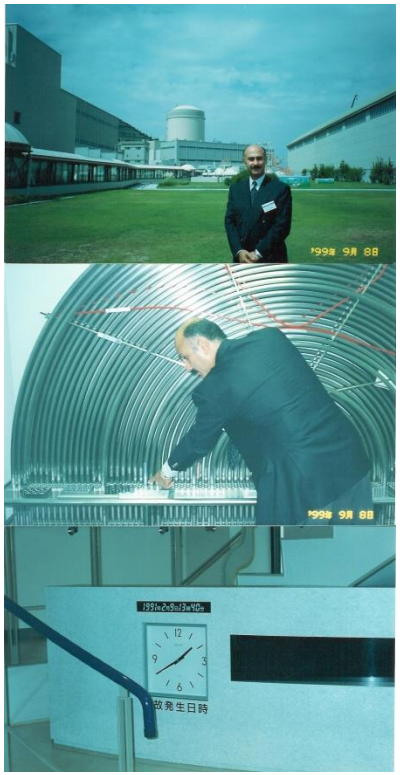
Last 30 years of working directly with and experience with:

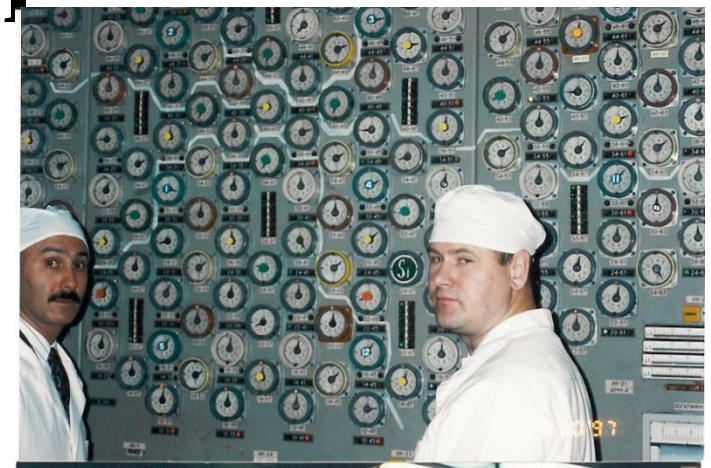
- **Nuclear power**
- **Petrochemical**
- **Refining**
- **Oil & Gas Pipeline**
- **Offshore Drilling**
- **Aviation**
- **Railroad**
- **Maritime**
- **Coal Mining**

And most recently (last 15+ years) with **Health Care** industries

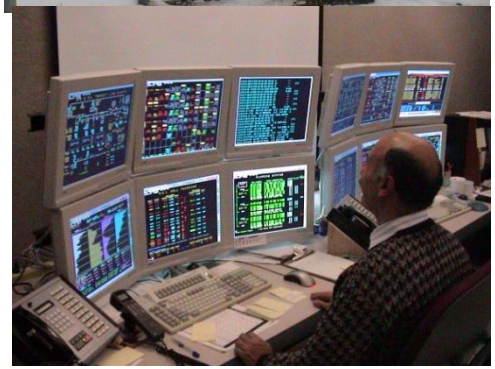
Nuclear Power







Petrochemical/Oil Industry

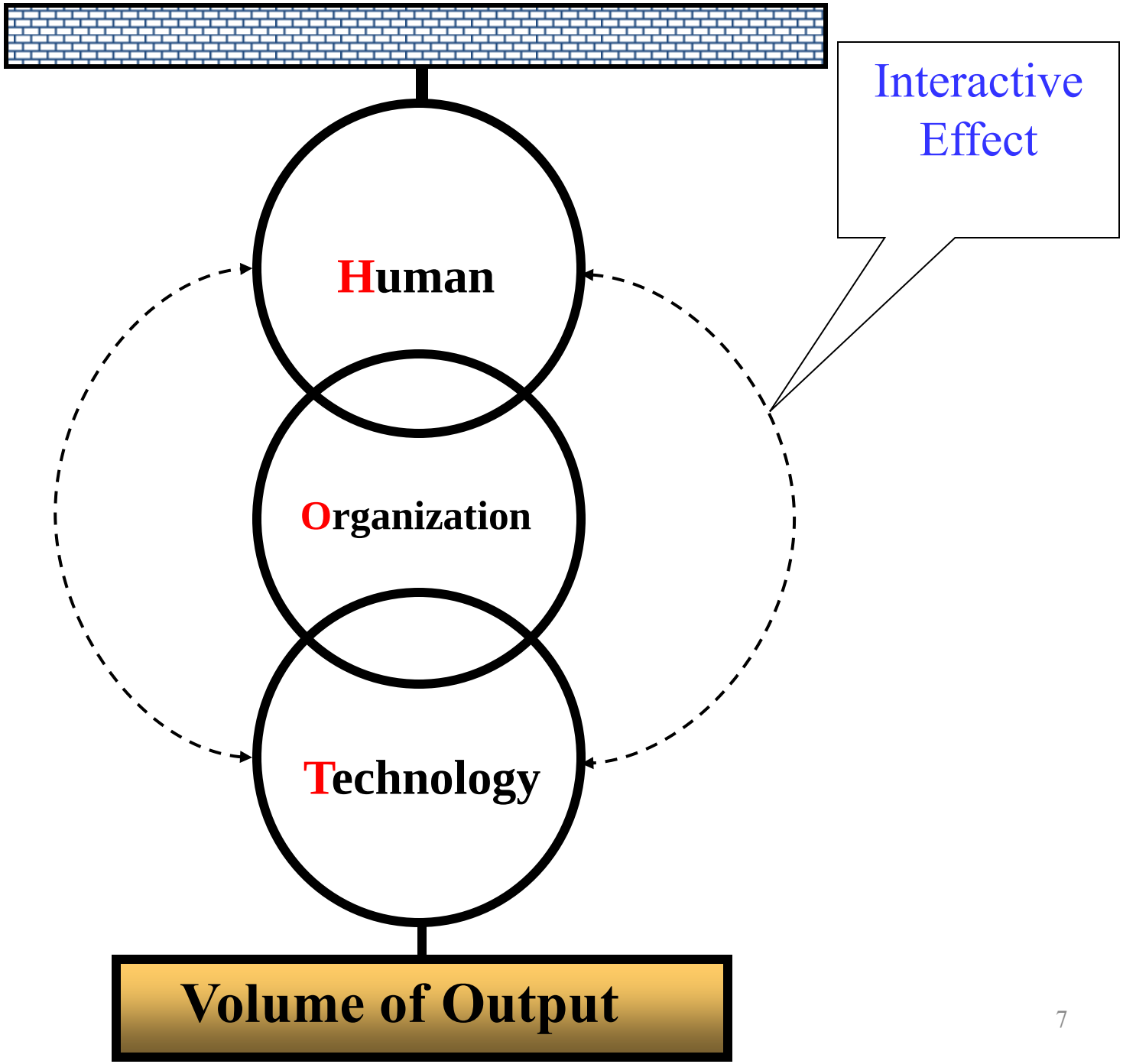


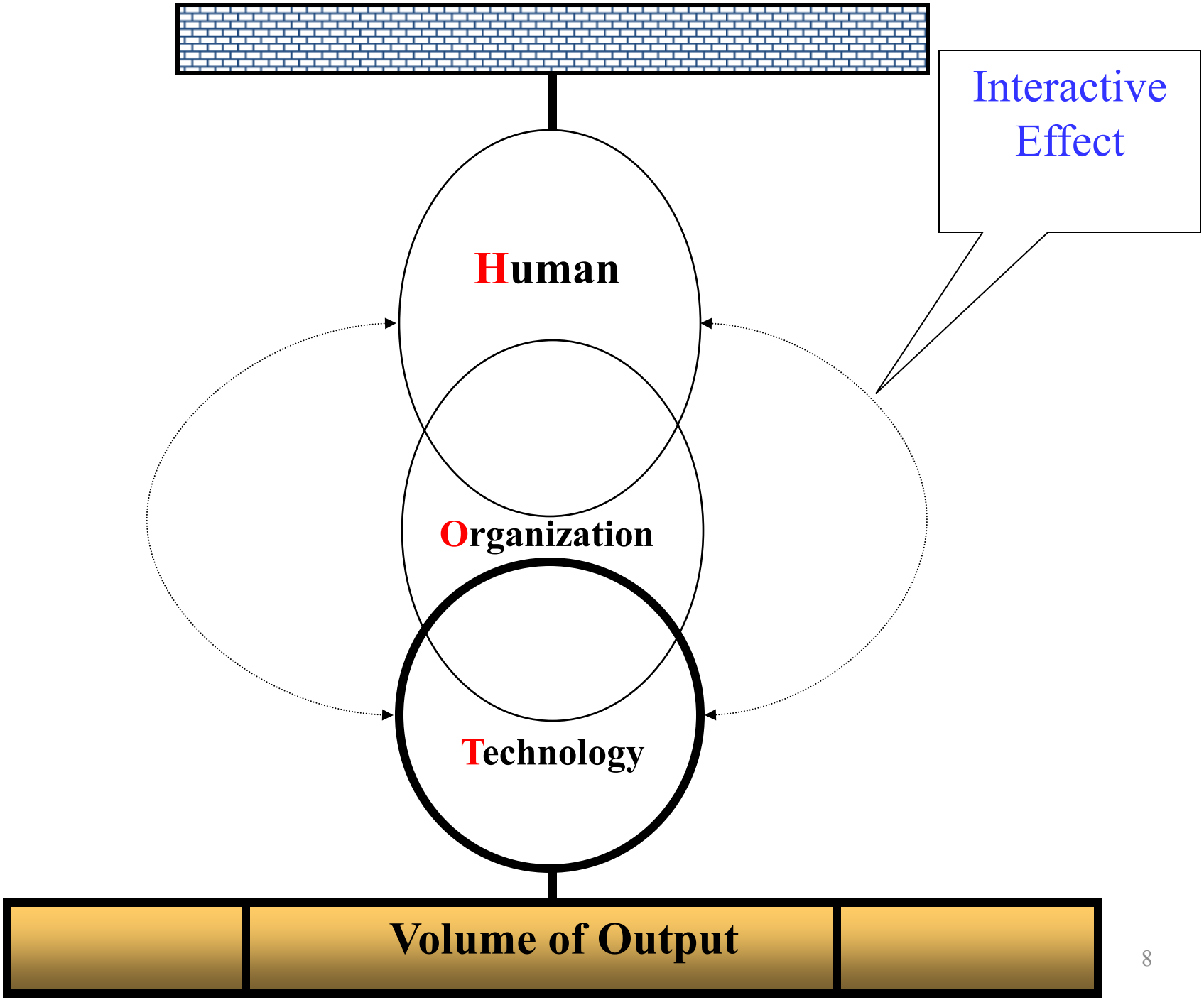
My Premise

Safety and Reliability of Complex Technological System

The 'HOT' Model

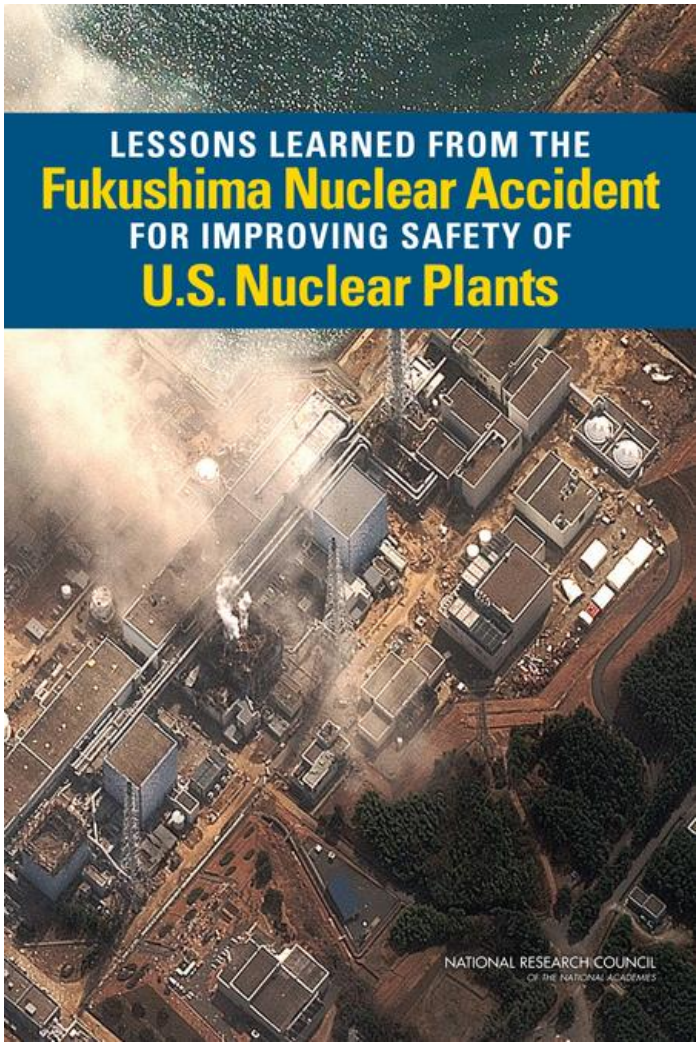
Major Subsystems of a Complex Technological System (e.g., a nuclear power plant, refinery, offshore oil platform)


Interactive Effect
Human
Organization
Technology
Volume of Output


Interactive Effect
Human
Organization
Technology
Volume of Output

NAS Fukushima Committee Report

Released June 24, 2014



Committee on Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Plants

NORMAN P. NEUREITER, *Chair*, American Association for the Advancement of Science, Washington, District of Columbia
B. JOHN GARRICK, *Vice Chair*, Independent Consultant, Laguna Beach, California
ROBERT A. BARI, Brookhaven National Laboratory, Upton, New York
PERCY M. BEARD, JR., Institute of Nuclear Power Operations (retired), Atlanta, Georgia
JAN BEYEA, Consulting in the Public Interest, Lambertville, New Jersey
M. QUINN BREWSTER, University of Illinois at Urbana-Champaign
MICHAEL L. CORRADINI, University of Wisconsin-Madison
RICHARD S. DENNING, The Ohio State University, Columbus [1]
VIJAY K. DHIR, University of California, Los Angeles
MICHAEL W. GOLAY, Massachusetts Institute of Technology, Cambridge
BARBARA L. HAMRICK, University of California, Irvine Medical Center
SHELLEY A. HEARNE, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, and Big Cities Health Coalition, National Association of County and City Health Officials, Washington, District of Columbia
PAUL A. LOCKE, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland
JAMES E. MATHESON, SmartOrg, Menlo Park, California
NAJMEDIN MESHKATI, University of Southern California, Los Angeles[2]
THOMAS G. MOSER, Osprey Global Solutions, Wilmington, North Carolina
ARTHUR T. MOTTA, Pennsylvania State University, University Park
JOHN A. ORCUTT, Scripps Institution of Oceanography, University of California at San Diego, La Jolla
EMILIE M. ROTH, Roth Cognitive Engineering, Menlo Park, California
JOSEPH E. SHEPHERD, California Institute of Technology, Pasadena
ELIZABETH Q. TEN EYCK, ETE Consulting, Inc., Great Falls, Virginia
MARK H. THIEMENS, University of California, San Diego[3]
FRANK N. VON HIPPEL, Princeton University, Princeton, New Jersey
LORING A. WYLLIE, JR., Degenkolb Engineers, San Francisco, California

Technical Advisor

NAJMEDIN MESHKATI, University of Southern California, Los Angeles[4]

Staff

KEVIN D. CROWLEY, Study Director
OURANIA KOSTI, Senior Program Officer
DANIEL POMEROY, Postdoctoral Fellow (December 10, 2012 to September 1, 2013)
DARLENE GROS, Senior Program Assistant

[1] Separated from committee on November 21, 2012
[2] Resigned from committee on June 12, 2013
[3] Resigned from committee on July 26, 2012
[4] Effective July 10, 2013


指差呼称

Two Case Studies

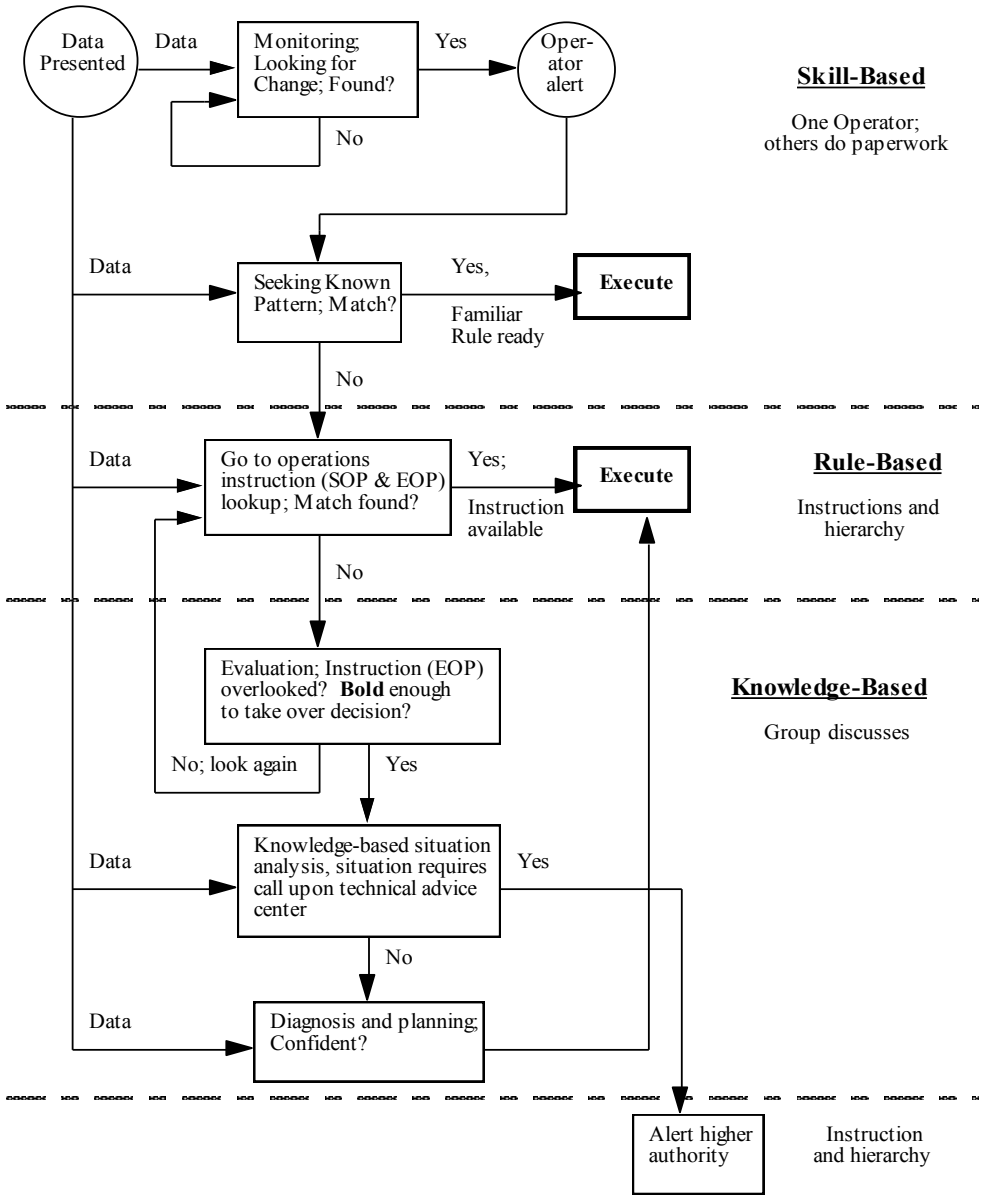
- **US Airways Flight 1549 - 2009**

  Miracle on the Hudson

- **Fukushima Daini Nuclear Power Station - 2011**

A Model for Nuclear Power Plant Operators' Responses to Disturbances (& Understanding Resiliency)

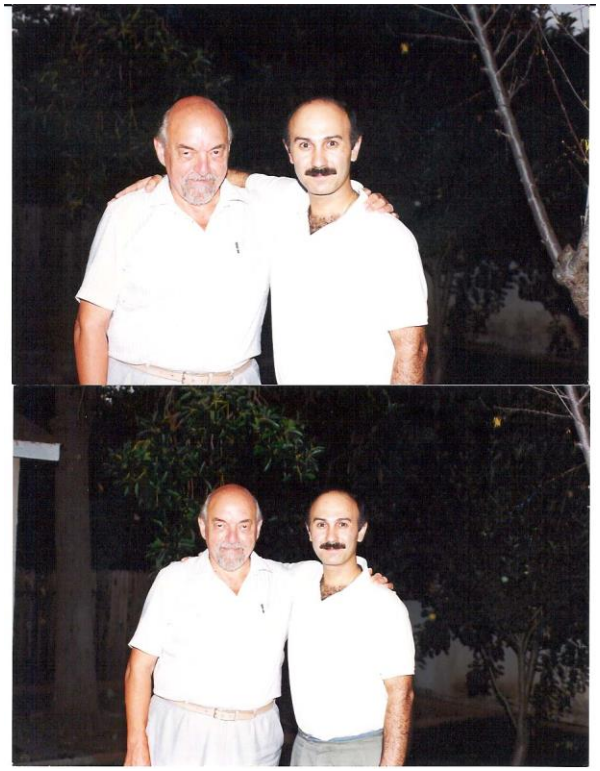
(From: Rasmussen, personal communication, 1992)



Professor Jens Rasmussen

"Operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination."

(1980, p. 97)



Los Angeles, 1992

Operators' Improvisation in Complex Technological Systems: Successfully Tackling Ambiguity, Enhancing Resiliency and the Last Resort to Averting Disaster

Najmedin Meshkati* and Yalda Khashe**

*Sonny Astani Department of Civil and Environmental Engineering, Daniel J. Epstein Department of Industrial & Systems Engineering, USC Viterbi School of Engineering, University of Southern California, Kaprielian Hall (KAP Bldg.), Room 238 B, Los Angeles, 90089-2531 CA, USA. E-mail: meshkati@usc.edu
**Daniel J. Epstein Department of Industrial and Systems Engineering, University of Southern California, Los Angeles, 90089-0193 CA, USA. E-mail: khashe@usc.edu

Complex safety-critical technological systems breakdowns, which are often characterized as 'low probability, high consequence', could pose serious threats for workers, the local public, and possibly neighboring regions and the whole country. System designers can neither anticipate all possible scenarios nor foresee all aspects of unfolding emergency. Front-line operators' improvisation via dynamic problem solving and reconfiguration of available recourses provide the last resort for preventing a total system failure. Despite advances in automation, operators should remain in charge of controlling and monitoring of safety-critical systems. Furthermore, at the time of a major emergency, operators will always constitute the society's both the first and last layer of defense; and it is eventually their improvisation and ingenuity that could save the day.

Operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination (Professor Jens Rasmussen, 1980, p. 97).

1. Introduction

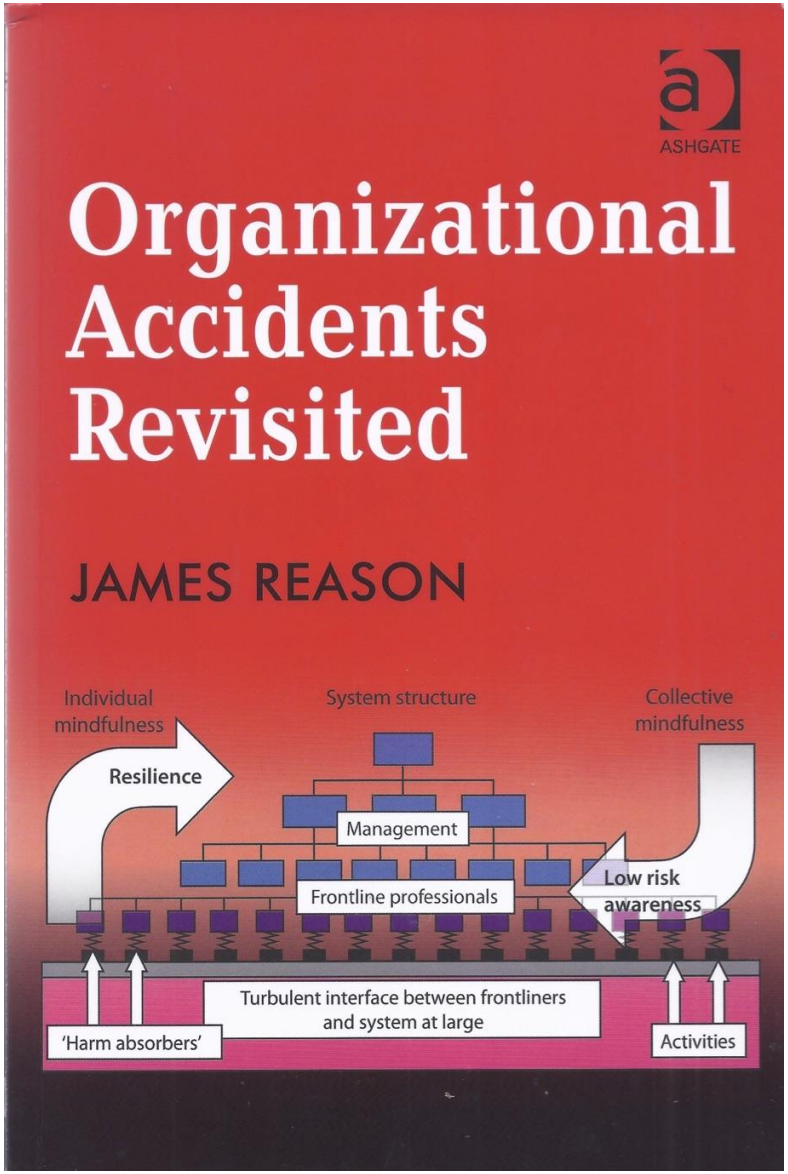
The 2009 astonishing emergency water 'landing' and safe evacuation of US Airways Flight 1549 has been called the 'Miracle on the Hudson'. Notable American philosopher and psychologist William James (1842–1910) stated with prescience that 'great emergencies and crises show us how much greater our vital resources are than we had supposed' (emphasis added). This moment of celebrity and celebration is a focused moment to consider the greater factors (and actors) that converged and created this and other un-choreographed but beautiful ballet of rescue and survival.

The Presidential Policy Directive 21 (Office of the Press Secretary, 2013) defines resilience as the ability to 'prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions'. This is similar to the generic definition of resiliency, as 'the power or ability to return to the original form, position, etc., after being bent, compressed, or stretched; elasticity'. Without understanding the vital role of human and organizational factors in technological systems and proactively addressing/facilitating their interactions

 DOI: 10.1111/1468-5973.12078

"I cannot end without once more expressing my enormous indebtedness to Professor Najmedin Meshkati and his co-author, Yalda Khashe. Their paper, 'Operators' Improvisation in Complex Technological Systems: Successfully Tackling Ambiguity, Enhancing Resiliency and the Last Resort to Averting Disasters', was published in the *Journal of Contingencies and Crisis Management* . In 2008, I wrote a book entitled The Human Contributions: Unsafe Acts, Accidents and Heroic Recoveries. Their paper goes well beyond what I wrote there or had thought about."

Professor James Reason [*Organizational Accidents Revisited* (2016), p.135]



Fukushima Accident

March 11, 2011

Loss of all power sources due to the Earthquake and Tsunami

Note:
-All operating units when earthquake occurred were automatically shut down.
-Emergency D/Gs have worked properly until the Tsunami attack.

① Loss of offsite power due to the earthquake

Grid Line

Tsunami (estimated more than 10m)

Turbine Building

Reactor Building

D/G

Elevation: about 10m

Seawater level

Seawater Pump

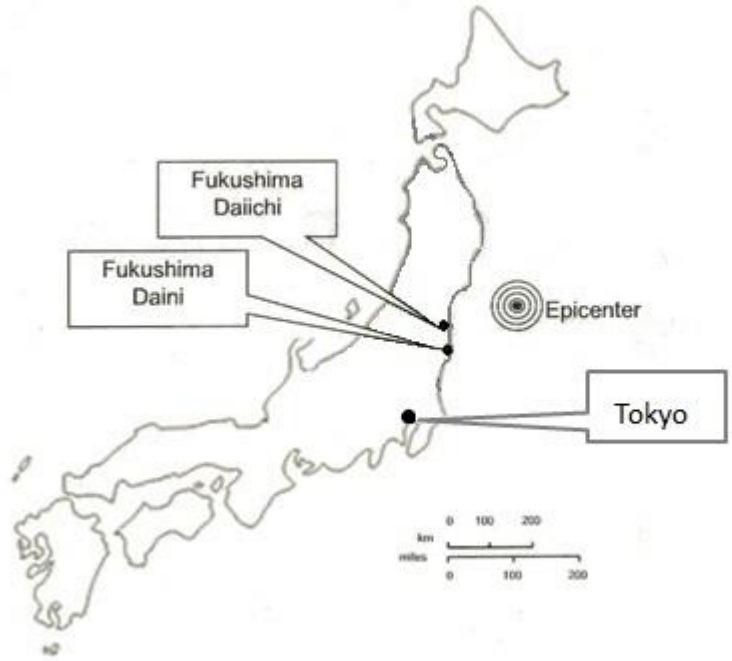
② D/G Inoperable due to Tsunami flood

①+② ⇒ Station Black Out

All Motor Operated pumps (including ECCS pumps) became inoperable

Source: Nuclear and Industry Safety Agency(NISA), April 4, 2011, at IAEA
http://www.nisa.meti.go.jp/english/files/en20110406-1-1.pdf

A few words about Daini..


Fukushima
Daiichi
Fukushima
Daini
Epicenter
Tokyo
0 100 200
km
miles
0 100 200

Outline and layout of the power plant

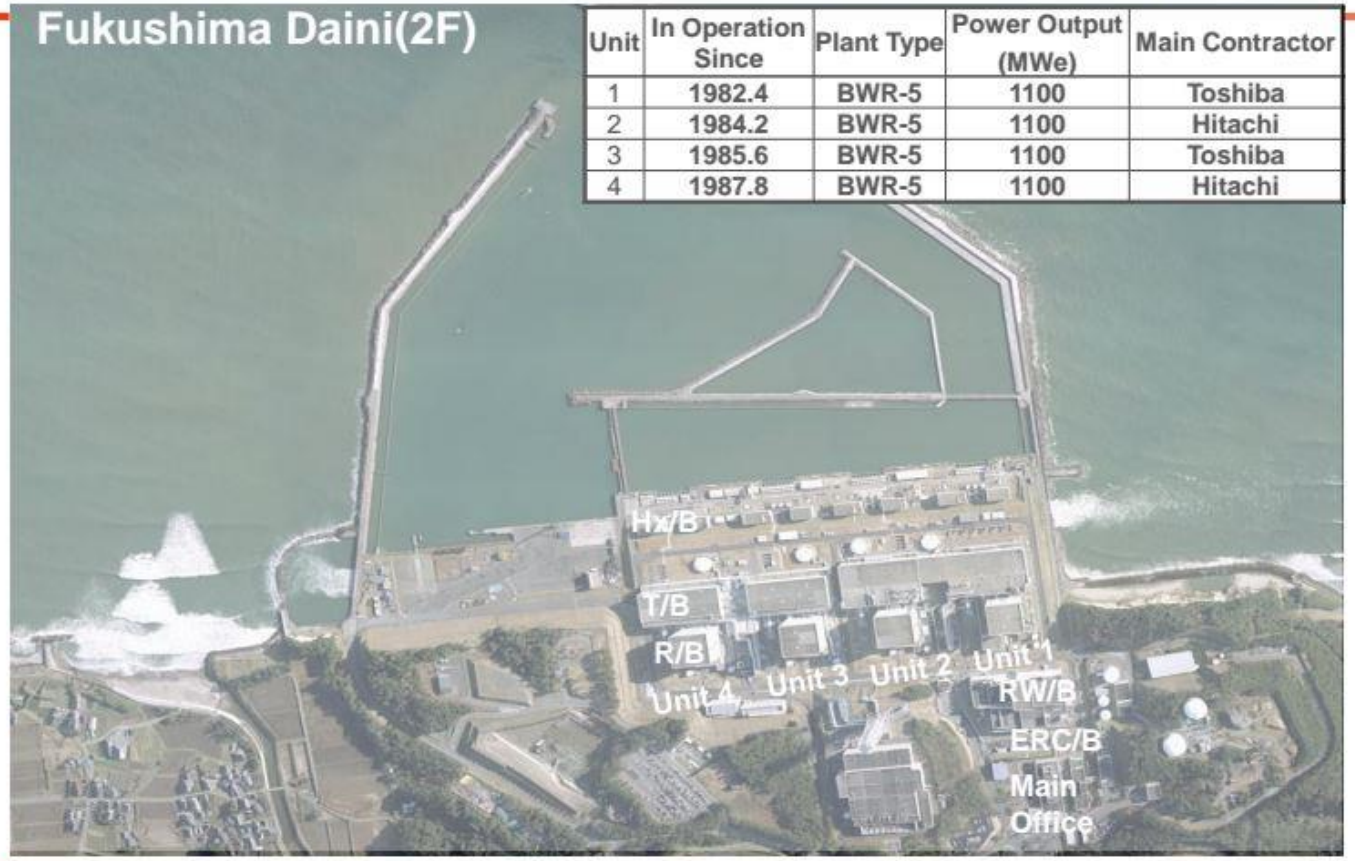
Outline of the power plant

Location：210km northeast of Tokyo.
Units 1 and 2 are in Naraha-town and units 3 and 4 are in Tomioka-town.

Site ：1.5km^2,1.5km from north to south, 1km east to west.

	Unit 1	Unit 2	Unit 3	Unit 4
Reactor type	BWR 5 Mark Ⅱ	BWR 5 Improved Mark Ⅱ	BWR 5 Improved Mark Ⅱ	BWR 5 Improved Mark Ⅱ
Thermal power	3,293 MWt			
Electrical power	1,100 MWe			
Commercial operation	April, 1982	Feb, 1984	June, 1985	August, 1987
Fuel assembly	764			
Control rod	185			
Main constructor	Toshiba	Hitachi	Toshiba	Hitachi

Overview of Fukushima Daini Nuclear Power Station



Unit	In Operation Since	Plant Type	Power Output (MWe)	Main Contractor
1	1982.4	BWR-5	1100	Toshiba
2	1984.2	BWR-5	1100	Hitachi
3	1985.6	BWR-5	1100	Toshiba
4	1987.8	BWR-5	1100	Hitachi

TOKYO ELECTRIC POWER COMPANY

From Mr. Naohiro Masuda's presentation on March 2014

The Unsung Heroes of Fukushima

The Japan Times

August 25-26, 2014

The Japan Times OPINION

COMMENTARY / JAPAN

The unsung heroes of Fukushima

BY NAJMEDIN MEISHAT

SPECIAL TO THE JAPAN TIMES

ARTICLE HISTORY | AUG 25, 2014

LOS ANGELES – Born in Iran 60 years ago, I have been a professor of engineering in the United States for almost 30 years. I am also a staunch fan of Japan and a die-hard admirer of Adm. Togo Heihachiro. I made sure to pay homage to him during my first trip to Japan, while on my way to Tsuruga, on Sept. 6, 1999, by visiting the Togo Shrine in Harajuku, Tokyo.

Togo showed exemplary leadership and tactics during the Russo-Japanese War, especially in his victory at the Battle of Tsushima in 1905, when he fought a formidable enemy against all odds. Although heavily outgunned, he ingeniously choreographed his underdog forces by "crossing the enemy's T." His decimation of the Russian Baltic fleet in just two days shocked the world.

It was the admiral's leadership, flexible strategic thinking, situational awareness and dynamic decision-making that enabled him and his dedicated sailors to win the uphill battle, stop the foe and save their country.

I believe the same admirable level of leadership, fortitude, dedication and stratagem was employed by the superintendent of the Fukushima No. 2 (Daini) nuclear power plant, Naohiro Masuda, and his 200 dedicated colleagues on March 11, 2011. After the earthquake and tsunami, they faced the loss of offsite power and a plant blackout.

Masuda also fought against the odds, improvising, making lots of impromptu but prudent decisions, and eventually saving the day by bringing all four reactors to a cold shutdown by March 15.

Their historic, heroic acts are too numerous to mention. The most remarkable included "flexibly applying emergency operating procedures" and having "9 km of temporary cable laid by about 200 personnel within a day." Such cable laying would usually take 20 people more than a month.

Fukushima No. 2 staff's personal sacrifices and dedication of staying in the plant and working under dire conditions, even though they didn't know whether their families had survived the earthquake-tsunami, and their relentless efforts to bring the four reactors to cold shutdown are of epic proportion. They stopped the propagation of an accident that could have led to multiple meltdowns as well as saved their plant (which was 20 km closer to Tokyo than the Fukushima No. 1 (Daiichi) nuclear power plant and perhaps the region.

I believe that Masuda and his colleagues at Fukushima No. 2 deserve to be considered national heroes of Japan, like the revered Togo.

It is an undeniable fact that unexpected and "beyond design basis" events will occur. System designers cannot anticipate all possible scenarios of failure and hence are not able to provide pre-planned safety measures for every contingency. As such, for the foreseeable future — despite advances in "computationally strong" robust models and elegant mathematical techniques such as probabilities risk assessment — human operators will have to remain in charge of the day-to-day control and monitoring of nuclear power plants.

Fukushima No. 2 and No. 1 operators verified the fact that at the time of a major accident at a hazardous complex, human operators always constitute society's first and last layer of defense.

Without respecting and understanding the vital role of human factors in technological systems, and proactively addressing their performance during unexpected events, nuclear safety will only be a distant mirage, and resiliency will be an unattainable dream.

The recently released report of the U.S National Academy of Sciences (NAS), "Lessons Learned From the Fukushima Nuclear Accident for Improving the Safety and Security of U.S Nuclear Plants (www.nap.edu/catalog.php?record_id=18294 (http://www.nap.edu/catalog.php?record_id=18294)), which focuses more on Fukushima No. 1, affirmed this fact:

"The Fukushima Daiichi accident reaffirms the important role that people play in responding to severe nuclear accidents and beyond-design-basis accidents more generally. ...

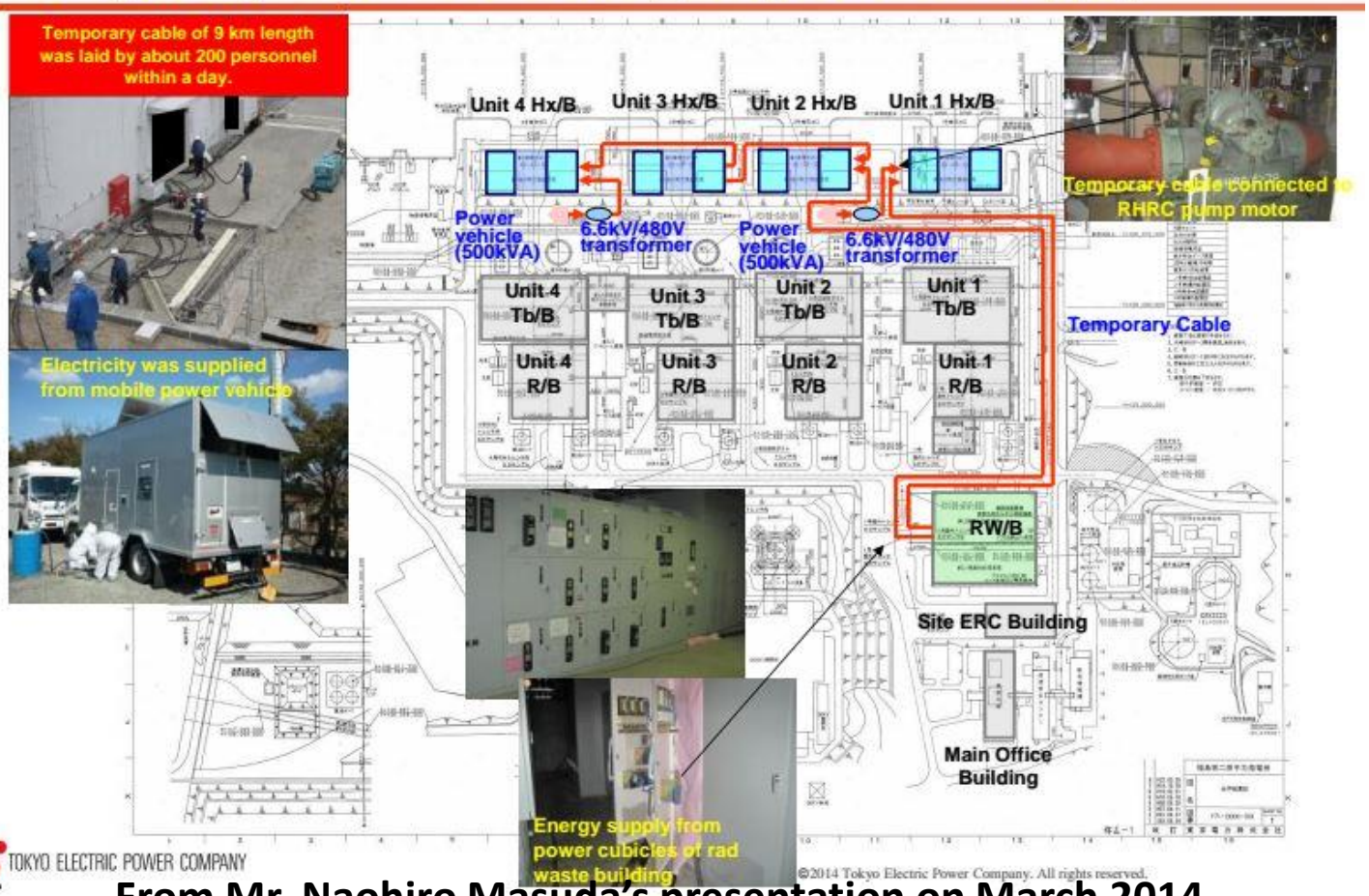
"Recovery ultimately depended on the ingenuity of the people on the scene to develop and implement alternative mitigation plans in real time. ...

"There is growing evidence that people are a source of system resilience because of their ability to adapt creatively in response to unforeseen circumstances. ... The Fukushima Daiichi accident reaffirmed that people are the last line of defense in a severe accident."

Masuda and Daini Personnel

- Impromptu, but prudent, decision-making
- Improvisation, e.g.,
- “flexibly applying Emergency Operation Procedures (EOPs)”
- “Temporary cable of 9 km length was laid by about 200 personnel within a day. Usually this size of cable laying requires 20 personnel and more than 1 month period.”

Temporary Cable for Emergency Power Supply



From Mr. Naohiro Masuda's presentation on March 2014

Narrator: “He [Mr. Masuda] remembers a creek used as a water supply during construction of the plant. Workers repair the leaky old pipe with a scavenged bicycle tube.”

A national hero of Japan in early 21st Century

Mr. Naohiro Masuda

Superintendent of the Fukushima Daini NPS

In Early 20th Century…

Japan's National Hero
Admiral Tōgō

Japan's National Hero
Marshal-Admiral Marquis Tōgō Heihachirō

The Togo Shrine, in Harajuku, Tokyo

In Early 21th Century…

A national hero

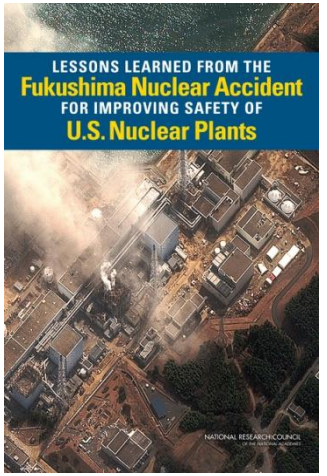
Mr. Naohiro Masuda

Superintendent of the Fukushima Daini Nuclear Power Station

Final Words
Conclusion

NAS Fukushima Committee Report

"The Fukushima Daiichi accident reaffirms the important role that people play in responding to severe nuclear accidents and beyond-design-basis accidents more generally...
Recovery ultimately depended on the ingenuity of the people on the scene to develop and implement alternative mitigation plans in real time…
There is a growing evidence that people are a source of system resilience because of their ability to adapt creatively in response to unforeseen circumstances…
The Fukushima Daiichi accident reaffirmed that *people are the last line of defense in a sever accident.*"
(emphasis added, p. J. 1& 3)



“Those who cannot remember the past are condemned to repeat it.”

G. Santayana [Reason in Common Sense (1905), p. 284]