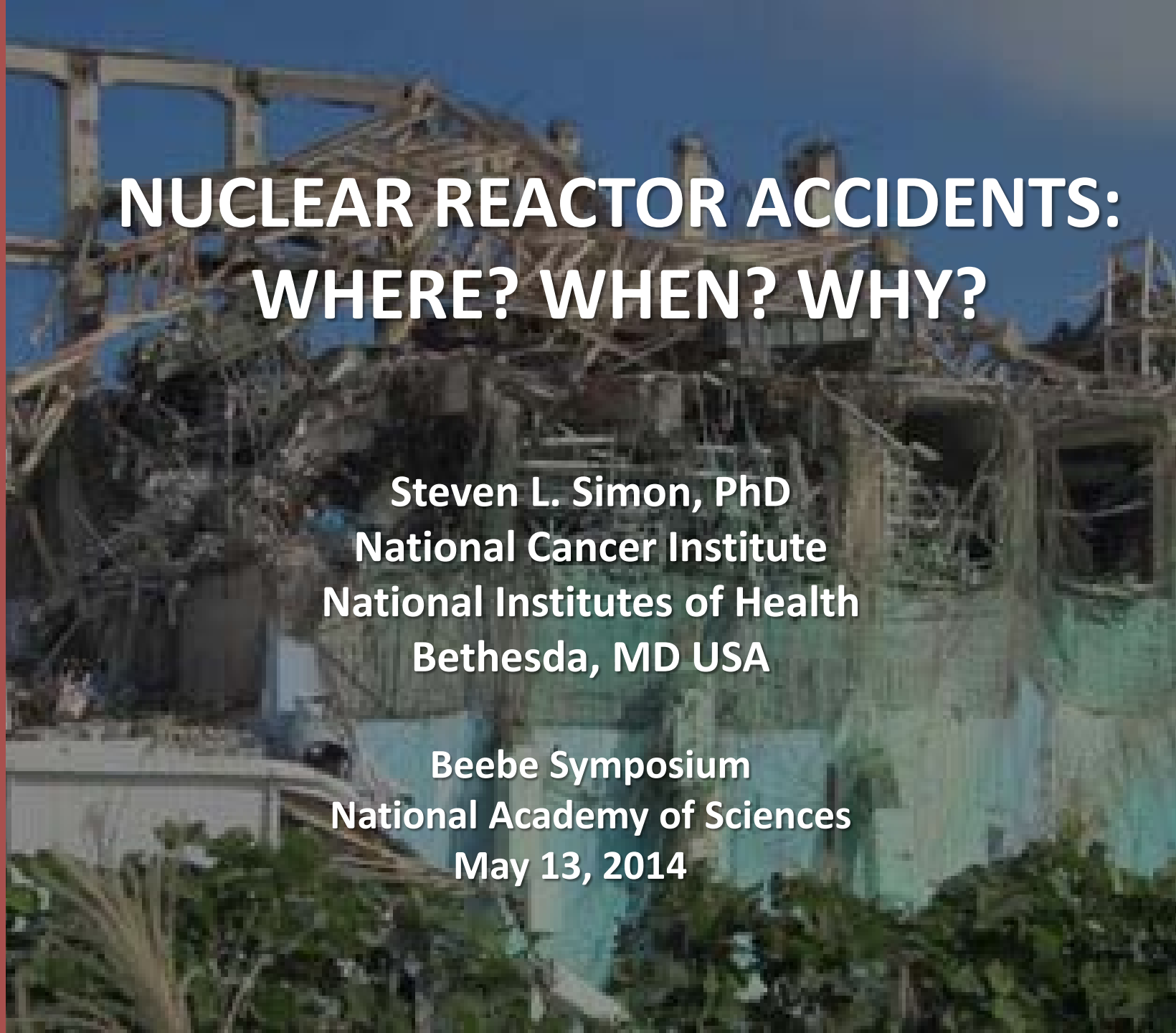


National Cancer Institute

NUCLEAR REACTOR ACCIDENTS: WHERE? WHEN? WHY?

Steven L. Simon, PhD
National Cancer Institute
National Institutes of Health
Bethesda, MD USA

Beebe Symposium
National Academy of Sciences
May 13, 2014

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

An ***accident*** is an unforeseen and unplanned event or circumstance, usually with a lack of intention.

Accident implies generally negative outcomes that might have been avoided or prevented had circumstances leading up to the accident been recognized, and acted upon, prior to its occurrence.

Accidents and disasters of all types occur every day – many with great similarities in the factors that underlie their cause – often poor judgment and engineering failures but, sometimes, acts of God. Some examples…

Investigator: Failed clamp caused circus accident

By **Michael Pearson**, CNN

updated 4:04 AM EDT, Wed May 7, 2014

"It was a single piece of equipment that failed," fire investigator told reporters.

Hot air balloon catches fire over Virginia;

By **Greg Botelho**, CNN

updated 11:29 PM EDT, Fri May 9, 2014

“…Most serious accidents …were due to pilot error… Ballooning is a very, very safe form of aviation.”

A **nuclear and radiation accident** is defined by the IAEA as "an event that has led to significant consequences to people, the environment or the facility." Examples include lethal effects to individuals, large radioactivity release to the environment, or reactor core melt.”

U.S. EPA definition of a 'radiation accident‘:

The unplanned or unexpected emission of radiation where it is likely that:

one or more persons have, or could have received an effective dose of radiation of at least:

5 millisieverts for an occupationally exposed person, or

1 milliseivert for any other person, or

…and the premises or environment may have become contaminated by radioactivity.

My own definition:

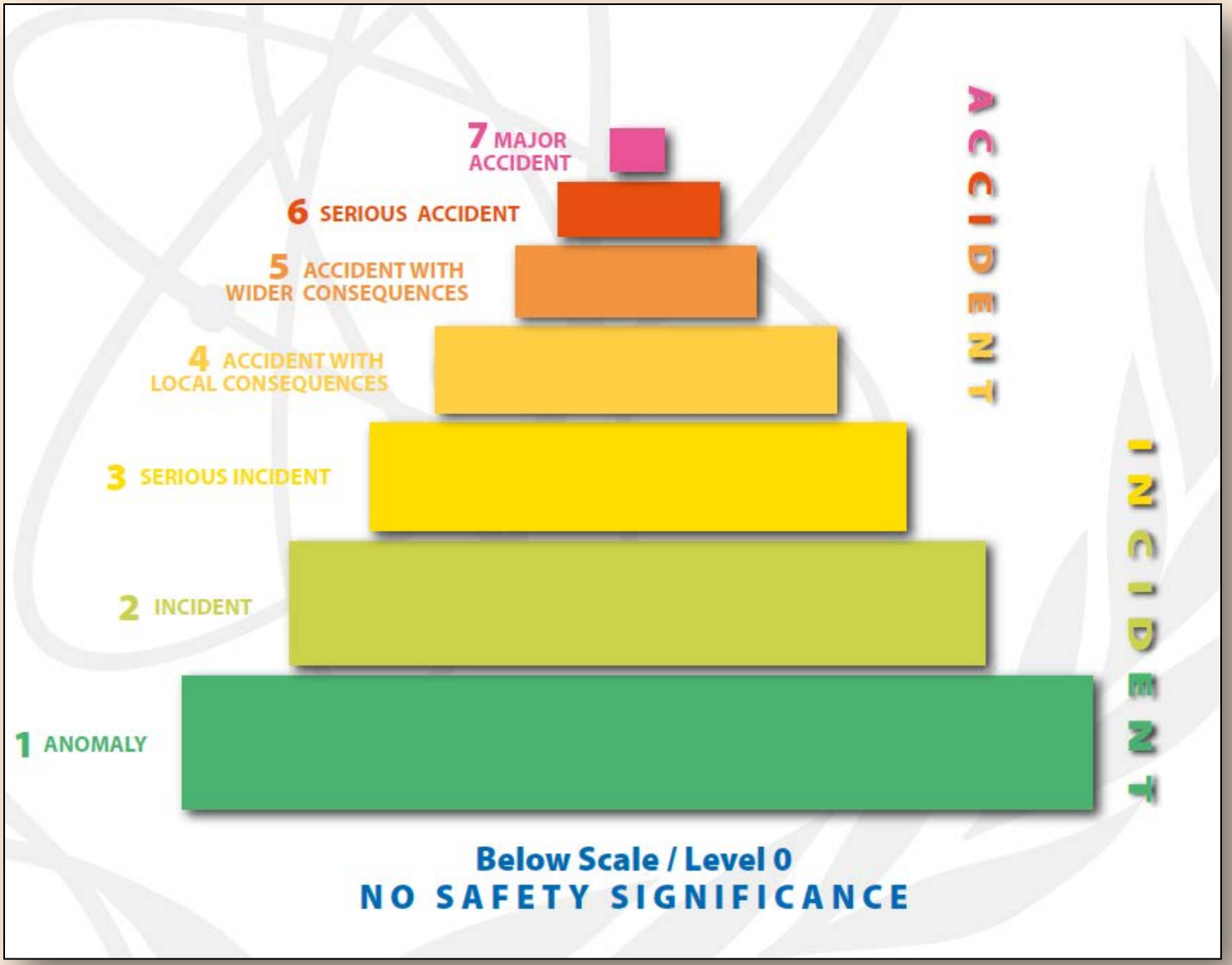
A nuclear **accident** is an unpredictable, unusual and unwanted event involving radiation and/or radioactive materials which results in occupational or public exposures and /or contamination of structures, property, or persons.

A nuclear reactor accident is just a special case scenario of "nuclear accidents."

-REB Radiation Epidemiology and Dosimetry Course Spring 2011

IAEA- International Nuclear and Radiological Event Scale

The scale is designed so that the severity of an event is about 10x greater for each increase in level on the scale.



Major Accident Level 7	• Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.	
Serious Accident Level 6	• Significant release of radioactive material likely to require implementation of planned countermeasures.	
Accident with Wider Consequences Level 5	• Limited release of radioactive material likely to require implementation of some planned countermeasures. • Several deaths from radiation.	• Severe damage to reactor core. • Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.
Accident with Local Consequences Level 4	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. • At least one death from radiation.	• Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. • Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.
Serious Incident Level 3	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.

Major Accident Level 7	• Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.	
Serious Accident Level 6	• Significant release of radioactive material likely to require implementation of planned countermeasures.	
Level 4	local food controls. • At least one death from radiation.	radioactive material within an installation with a high probability of significant public exposure.
Serious Incident Level 3	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.

- Limited release of radioactive material likely to require implementation of some planned countermeasures.
- Several deaths from radiation.

- Severe damage to reactor core.
- Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.

Major Accident Level 7	• Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.	
Serious Accident Level 6		
Accident with Wider Consequenc Level 5		
Accident with Local Consequences Level 4	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. • At least one death from radiation.	• Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. • Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.
Serious Incident Level 3	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.

• Significant release of radioactive material likely to require implementation of planned countermeasures.

Major Accident Level 7		
Serious Accident Level 6		
Accident with Wider Consequences Level 5	• Limited release of radioactive material likely to require implementation of some planned countermeasures. • Several deaths from radiation.	• Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.
Accident with Local Consequences Level 4	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. • At least one death from radiation.	• Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. • Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.
Serious Incident Level 3	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.

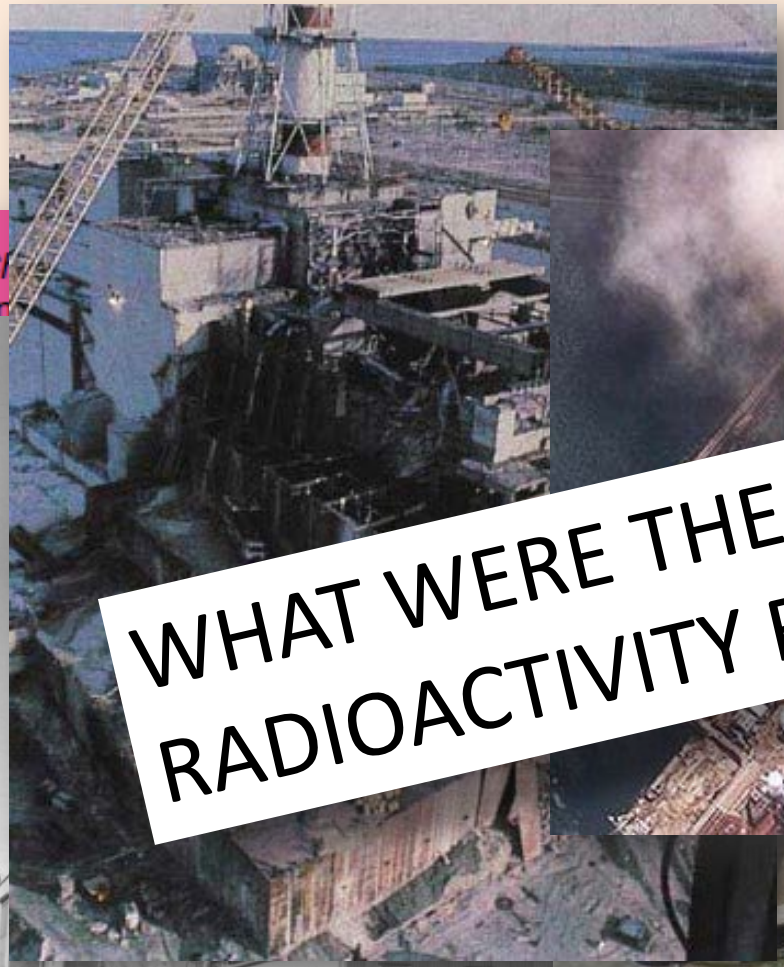
- Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.

7

6

5

4



WHAT WERE THE RADIOACTIVITY RELEASES?

Estimates of Iodine-131 released to the environment

I-131 Released Relative to Chernobyl	Geographic Location	Time Period
1*	Chernobyl (Ukraine)	1986
0.10	Fukushima NPP (Japan)	2011
0.0004	Windscale, UK	1957
0.0000003	Three Mile Island, PA	1979

*1,800 x 10^{15} Bq

Other radionuclides presented in emissions from nuclear power plant accidents (x 10^{15} Bq)

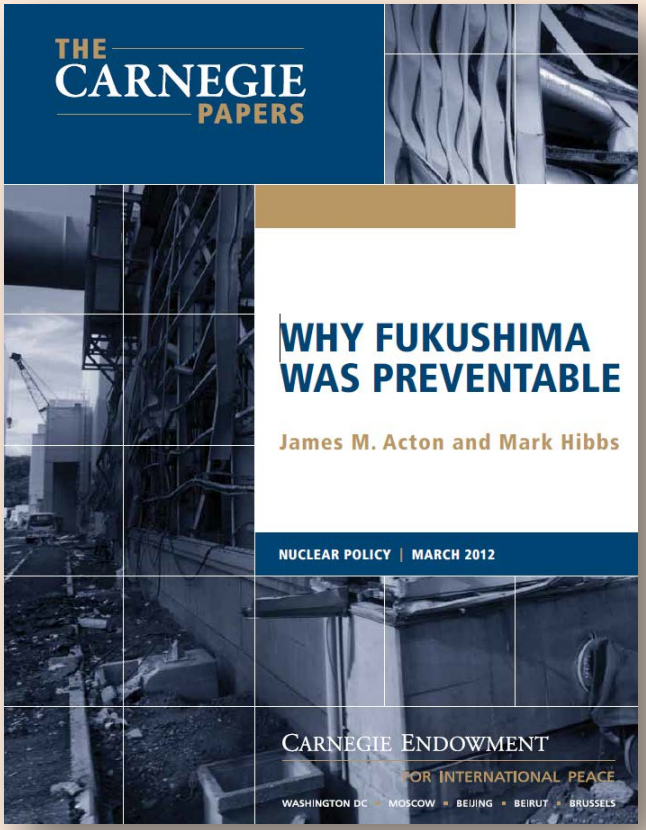
	^{131}I	^{137}Cs	^{90}Sr	Other
REACTORS:				
Windscale (1957)	**0.6**	**0.05**	**<0.001**	**^{210}Po**
TMI (1979)	**0.001**			**^{133}Xe**
Chernobyl (1986)	**1800**	**85**	**10**	**^{134}Cs, etc.**
Fukushima (2011)	**160**	**15**	**0.14**	**^{134}Cs, etc.**
OTHER:				
Kyshtym (1957)		0.26	4.0	^{144}Ce-Pr, etc.
Goiania (1987)		0.05		

In planning for the future use of nuclear power reactors, society needs to ask itself: ***What is an acceptable rate for severe nuclear power plant accidents?***

Once per 100 years of operation?

Once per 1,000 years of operation?

Once per 10,000 years of operation?



According to the Carnegie Endowment:

Two accidents have led to significant releases of radiation, which averages out to about 1 major release every 7,500 years of reactor operation (worldwide).

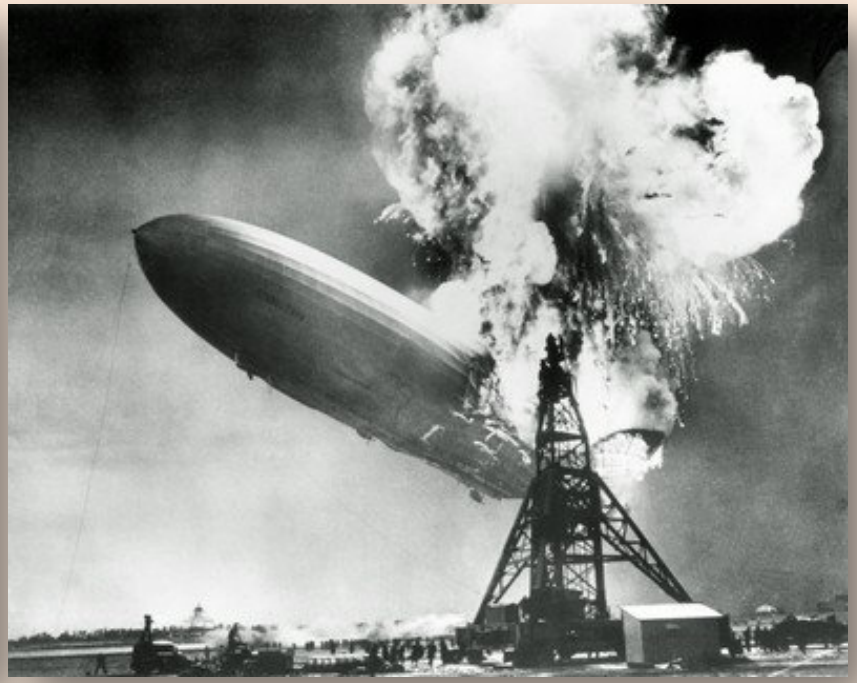
The IAEA's International Nuclear Safety Group believes that if best practices are implemented, major releases of radiation from existing nuclear power plants should occur about **15x** less frequently, or

1 per 112,500 years of operation.

Minimizing the frequency of reactor accidents (disasters) requires some understanding of the possible underlying causes of accidents, in general.

<u>Causes of accidents (in general)</u>:

1) **Human folly**
2) **Poor judgment (human error)**
3) **Mechanical failures (design failures)**
4) **Acts of nature (acts of 'God')**



<u>Cause of accident:</u>

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of ‘God’)?**

Cause of accident:

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of ‘God’)?**

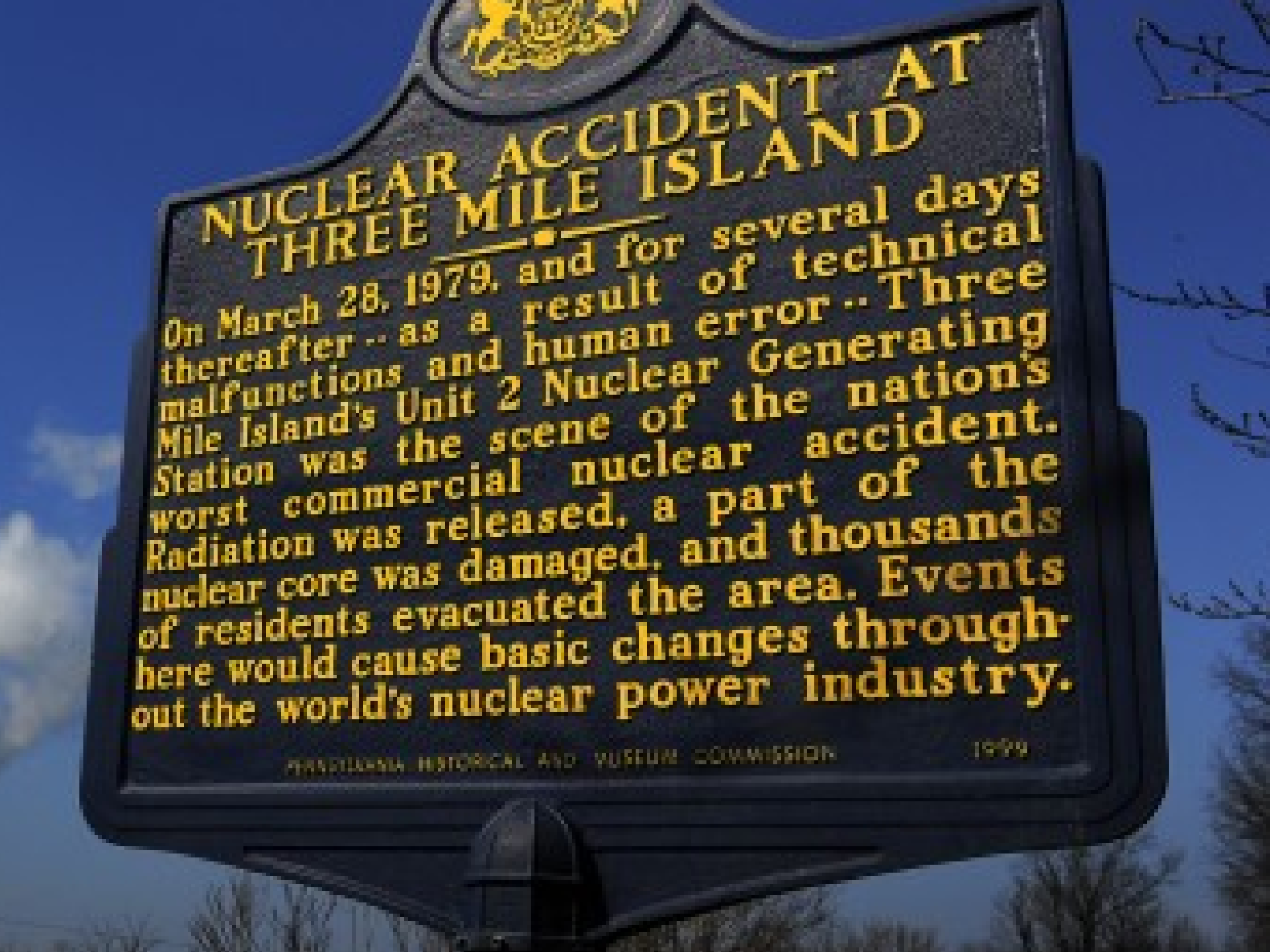
Cause of disaster:

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of 'God')?**

TMI

Cause of accident:

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of ‘God’)?**


NUCLEAR ACCIDENT AT THREE MILE ISLAND
On March 28, 1979, and for several days thereafter -- as a result of technical malfunctions and human error -- Three Mile Island's Unit 2 Nuclear Generating Station was the scene of the nation's worst commercial nuclear accident. Radiation was released, a part of the nuclear core was damaged, and thousands of residents evacuated the area. Events here would cause basic changes throughout the world's nuclear power industry.
PENNSYLVANIA HISTORICAL AND MUSEUM COMMISSION
1979

Cause of non-reactor disaster in Japan?

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of 'God')?**


Fukushima Diiachi reactor complex

Cause of accident:

1) **Human folly?**
2) **Poor judgment (human error)?**
3) **Mechanical failures (design failures)?**
4) **Acts of nature (acts of ‘God’)?**

“Japanese reactors are designed to survive earthquakes as strong as that which occurred on March 11, 2011, though the protection against the subsequent tsunami was totally inadequate.

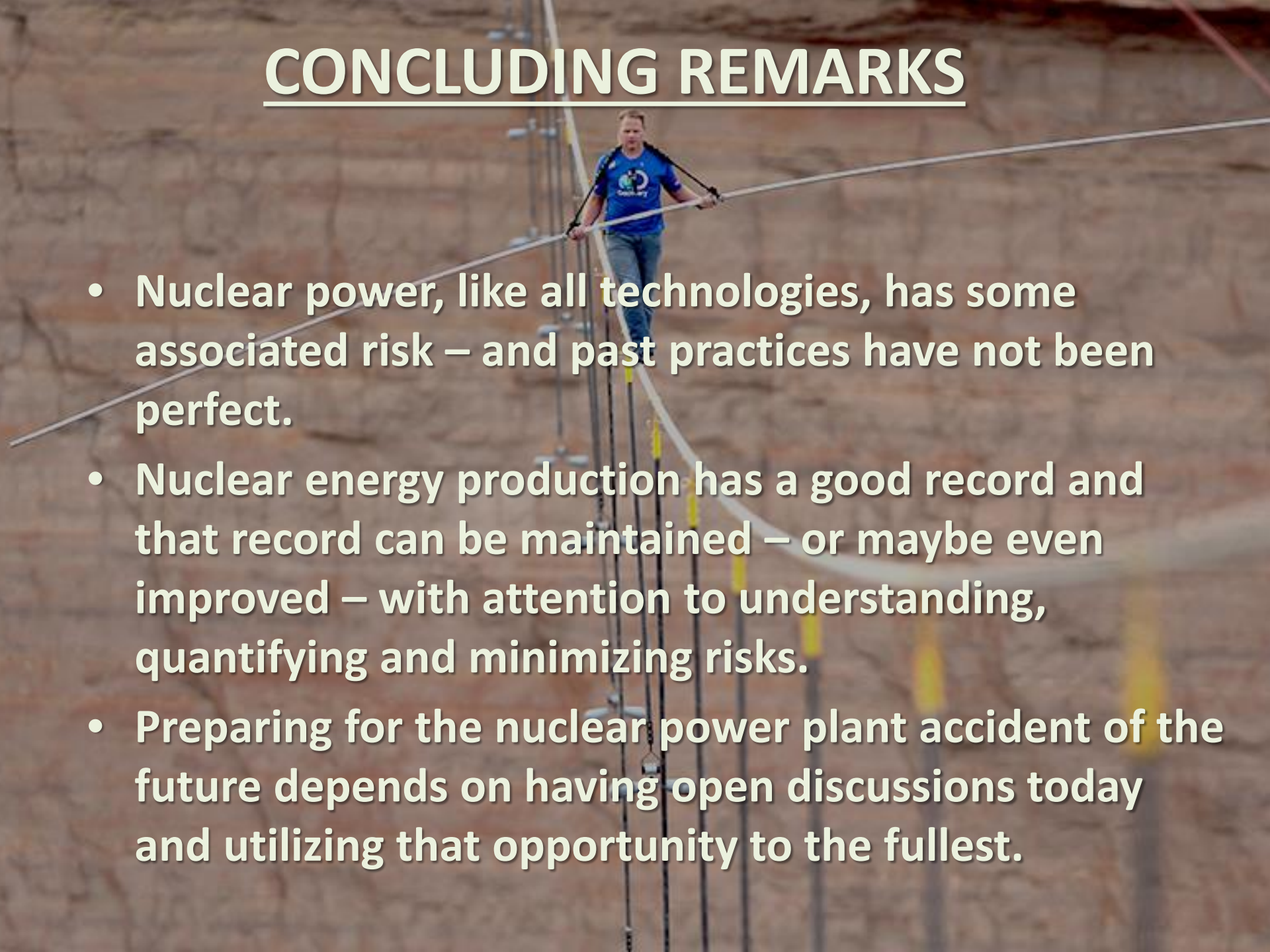
Historical records show that tsunami waves exceeding a height of 10–20 m have occurred several times in the past few hundred years.”

L. Hogberg, AMBIO 2013, 42:267–284

According to the World Nuclear Association (2013):

- There have been three major reactor accidents in the history of civil nuclear power - Three Mile Island, Chernobyl and Fukushima.
- One was contained without harm to anyone, the next involved an intense fire without provision for containment, and the third severely tested the containment, allowing some release of radioactivity.
- These are the only major accidents to have occurred in over 14,500 cumulative reactor-years of commercial nuclear power operation in 33 countries.
- The overall health risks from nuclear power plant accidents, in terms of the consequences, seem to be minimal compared with other commonly accepted risks. Nuclear power plants are generally very robust.

CONCLUDING REMARKS



- Nuclear power, like all technologies, has some associated risk – and past practices have not been perfect.
- Nuclear energy production has a good record and that record can be maintained – or maybe even improved – with attention to understanding, quantifying and minimizing risks.
- Preparing for the nuclear power plant accident of the future depends on having open discussions today and utilizing that opportunity to the fullest.