MODULE 6

Evolution of Safety

From technical to human and organizational factors

2025

ISIC-GSCP
Group of Chemical and Physical Safety

Source https://en.wikipedia.org/wiki/Skyscraper_design_and_construction

What we consider “safe” evolves with time

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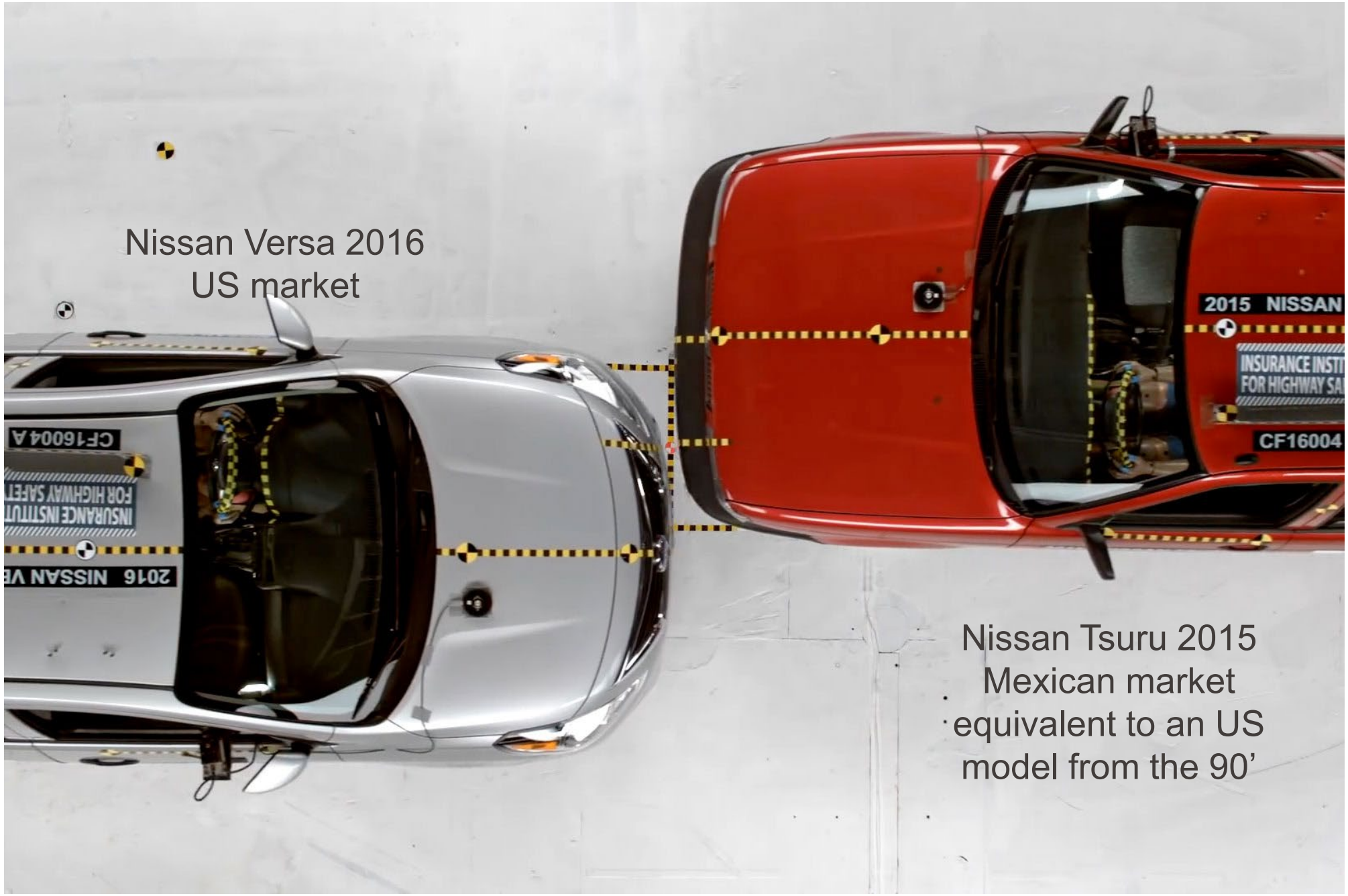
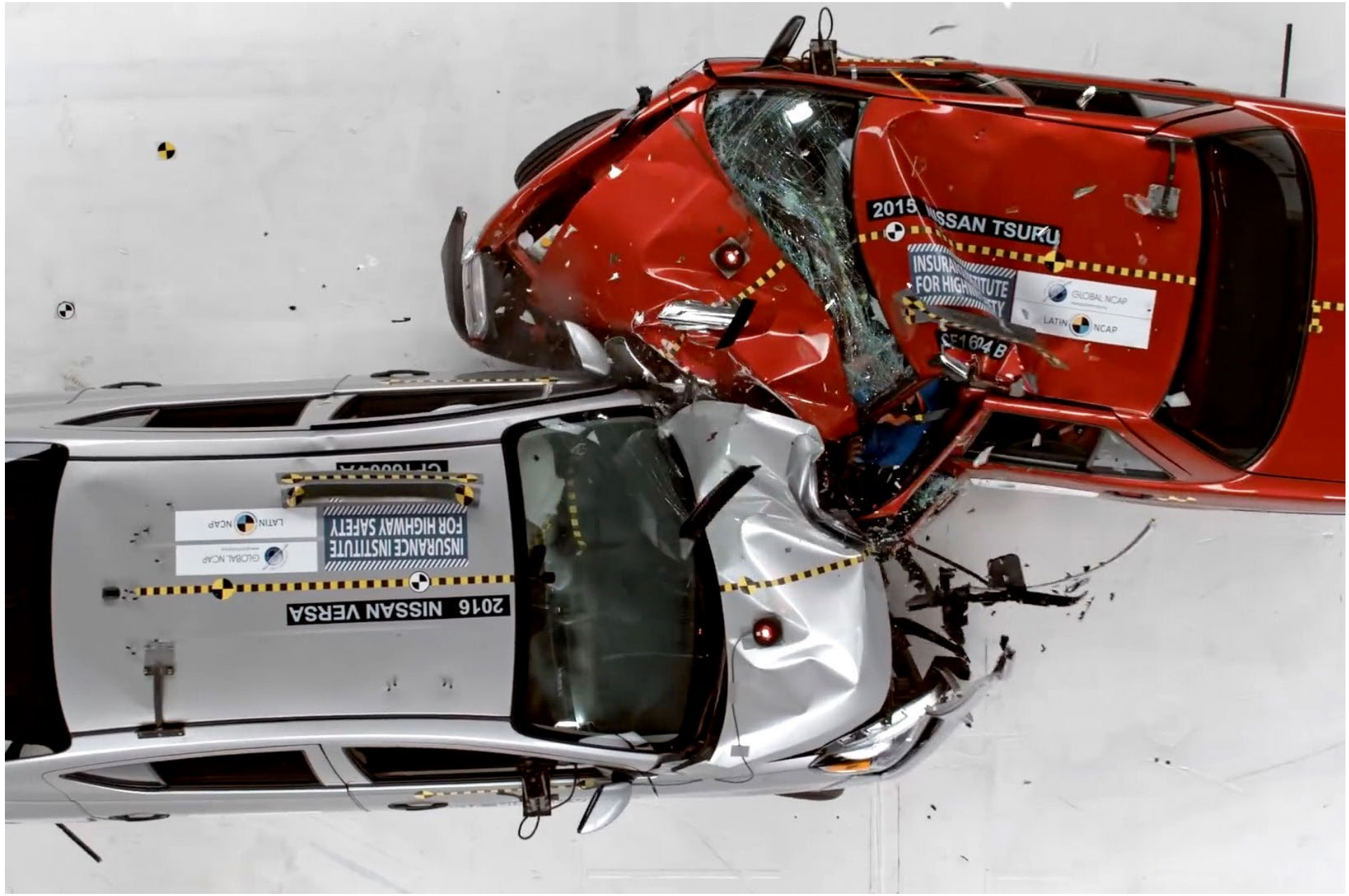


Source https://www.autoevolution.com/news/car-to-car-crash-test-forces-nissan-to-stop-production-of-zero-stars-tsuru-model-112634.html



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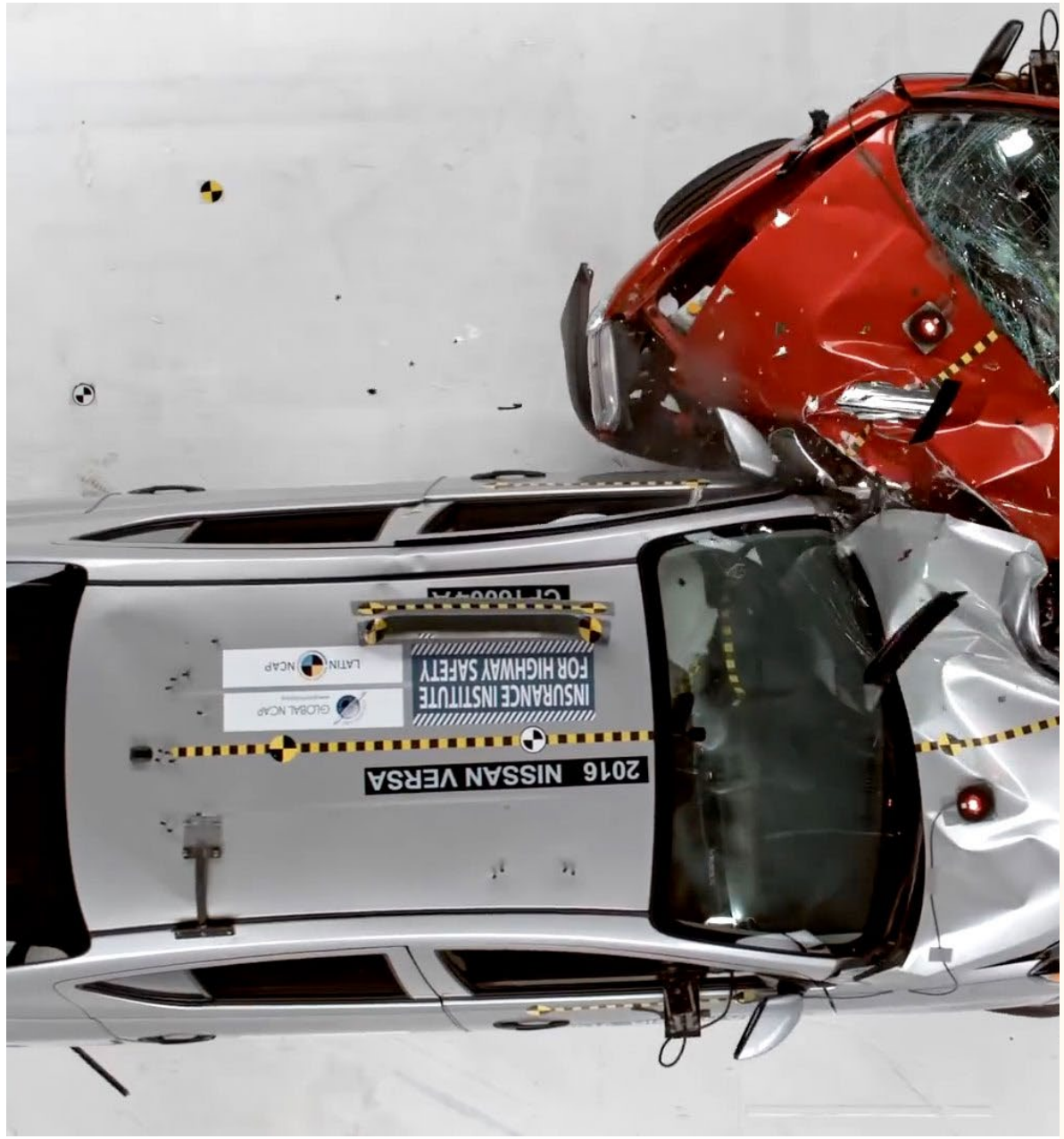
2016 NISSAN VERSA
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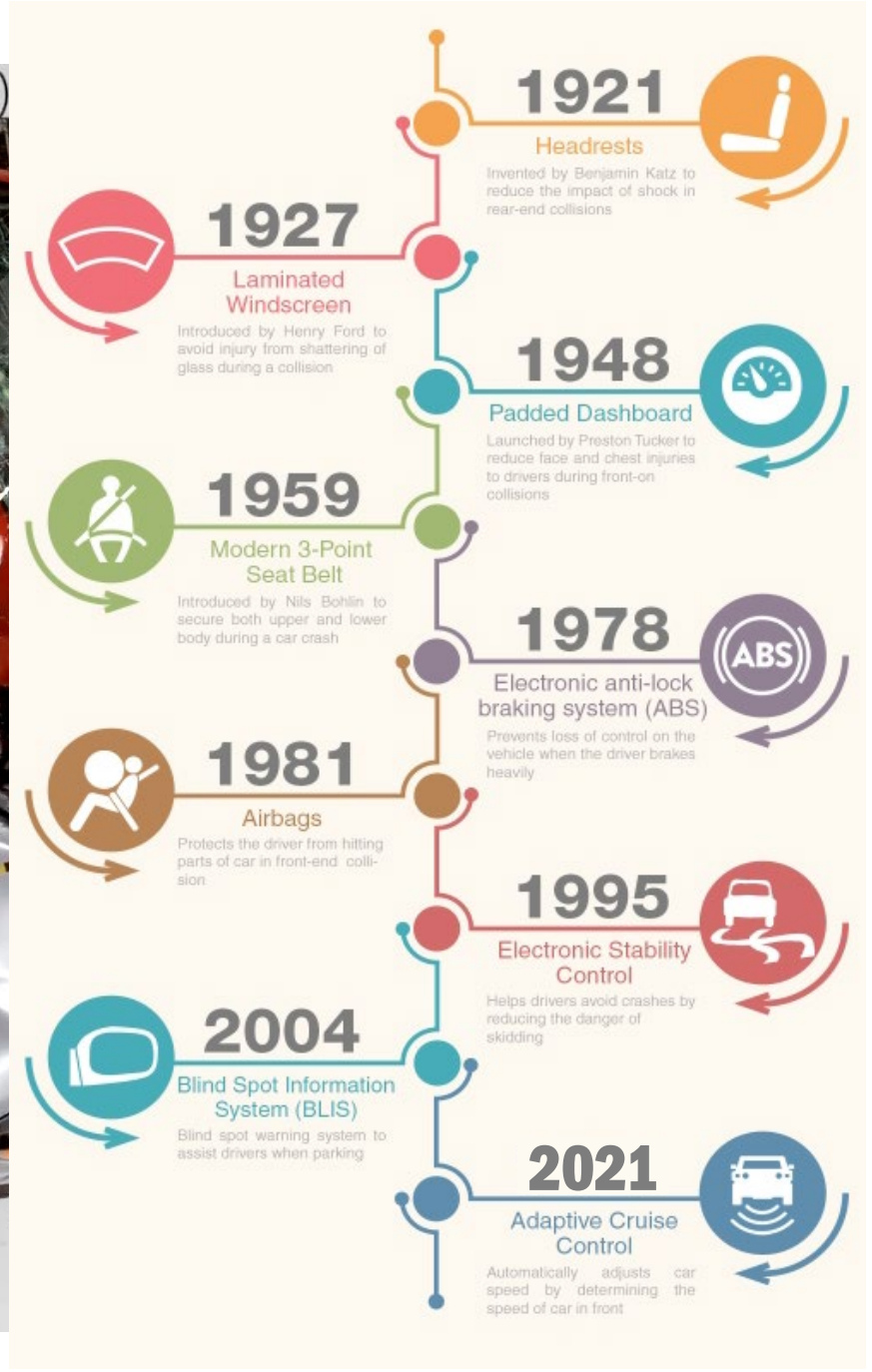
GLOBAL NCAP


1921
Headrests
Invented by Benjamin Katz to reduce the impact of shock in rear-end collisions
1927
Laminated Windscreen
Introduced by Henry Ford to avoid injury from shattering of glass during a collision
1948
Padded Dashboard
Launched by Preston Tucker to reduce face and chest injuries to drivers during front-on collisions
1959
Modern 3-Point Seat Belt
Introduced by Nils Bohlin to secure both upper and lower body during a car crash
1978
ABS
Electronic anti-lock braking system (ABS)
Prevents loss of control on the vehicle when the driver brakes heavily
1981
Airbags
Protects the driver from hitting parts of car in front-end collision
1995
Electronic Stability Control
Helps drivers avoid crashes by reducing the danger of skidding
2004
Blind Spot Information System (BLIS)
Blind spot warning system to assist drivers when parking
2021
Adaptive Cruise Control
Automatically adjusts car speed by determining the speed of car in front

The making of nitroglycerine in the 19th century

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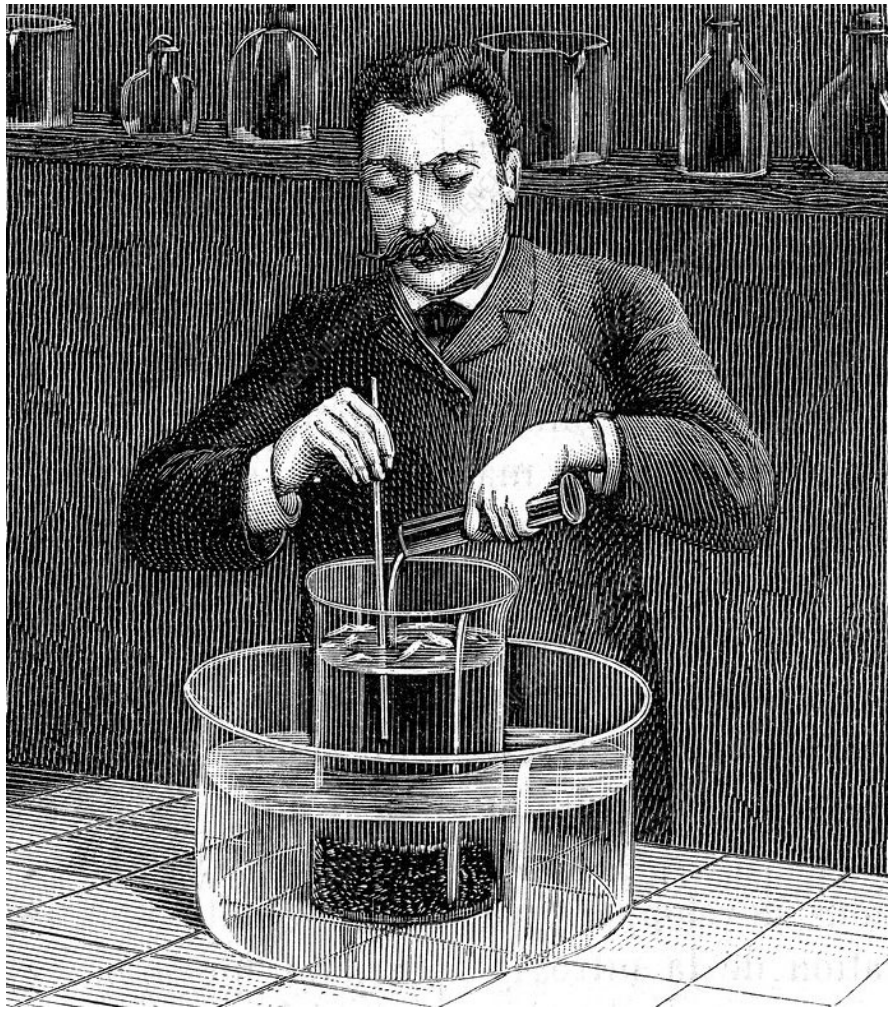


Alfred Nobel began manufacturing nitroglycerine in 1864.

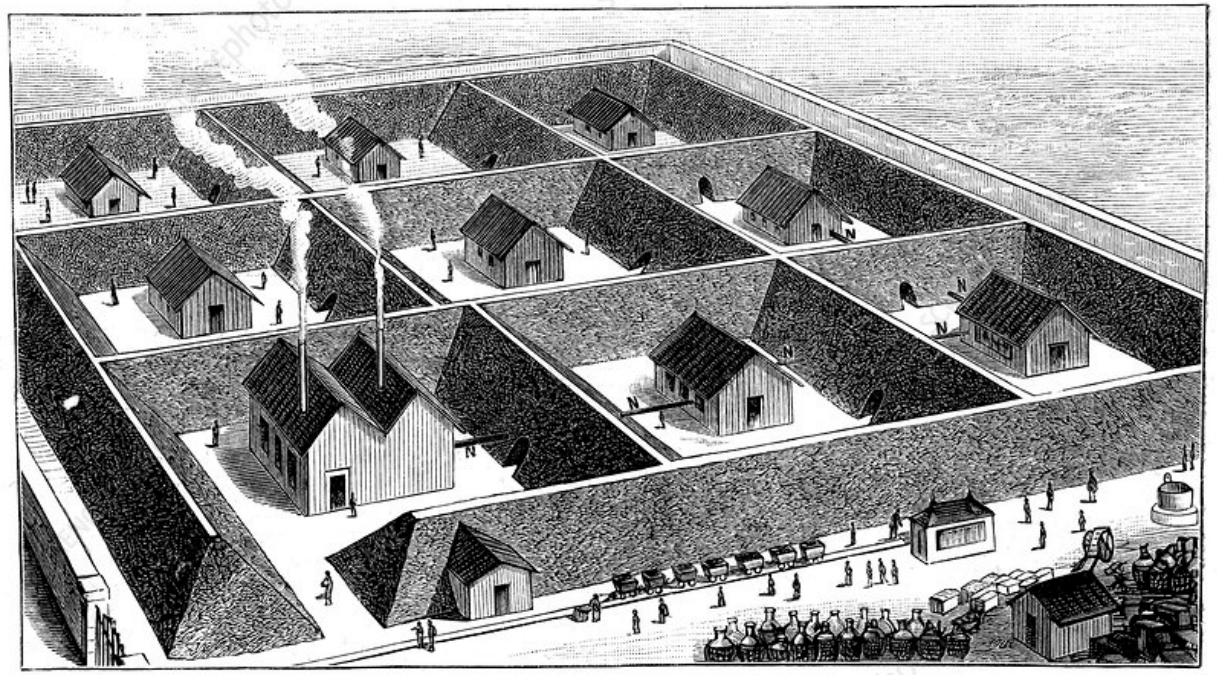
Process

- Fuming nitric acid and sulfuric acid are added to the glycerin.
- The reaction is exothermic, but the temperature **must be kept low** to prevent the newly formed nitroglycerin from exploding.

1889 illustration of a scientist making nitroglycerine in a laboratory.
Source: https://www.sciencephoto.com/media/818344/view/making-nitroglycerine-19th-century-illustration

Early safety measures and resilience

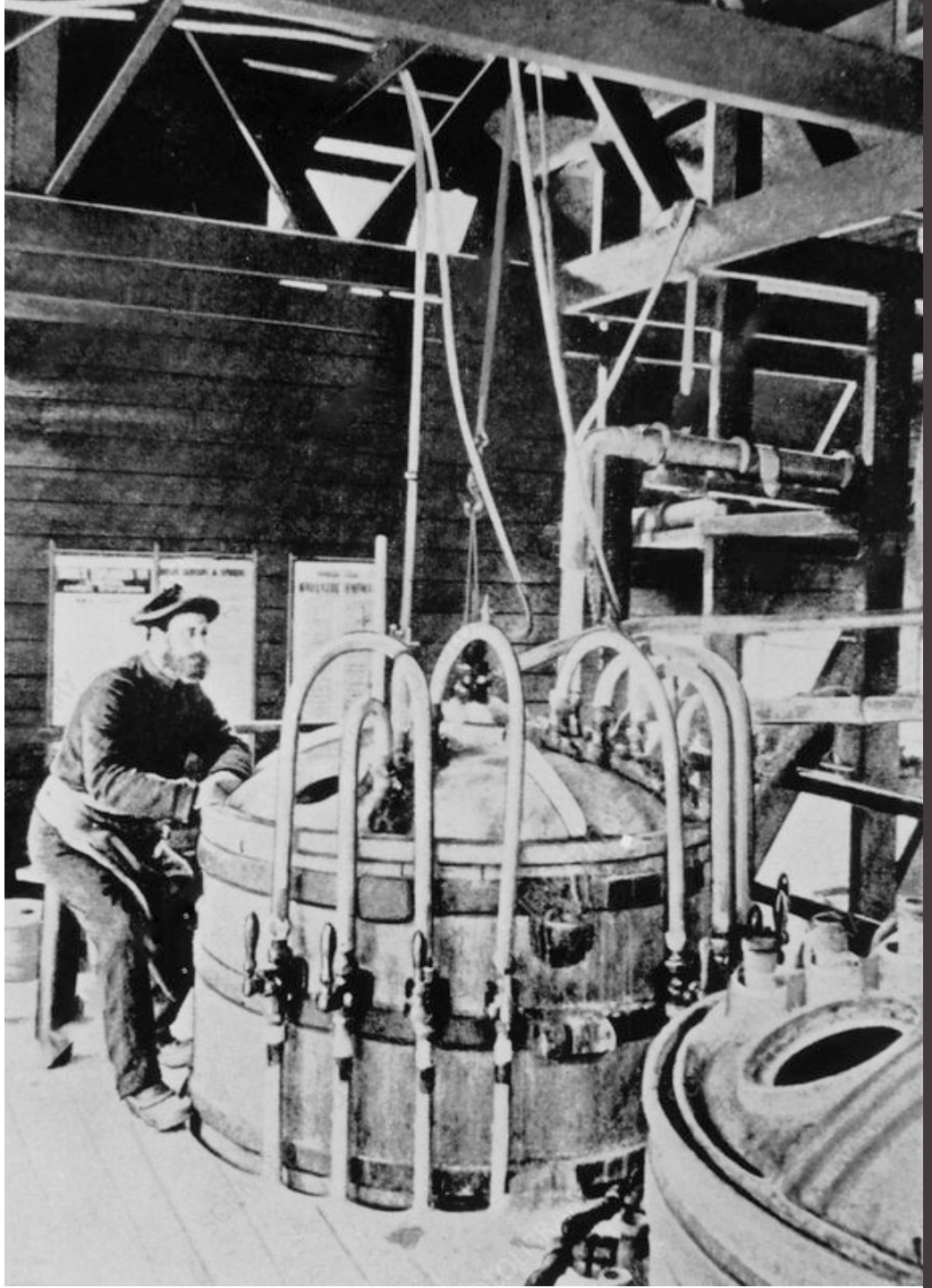
- Explosions were not uncommon, and Alfred Nobel's own brother was killed in such an explosion.
- By today's standards: **Is this solution acceptable?**



Nitroglycerin processing plant, Val Bormida, Italy, 1888.

Due to the instability of the materials used in its construction, earthen embankments separate each building and surround the entire complex. The roofs of the buildings have not been fixed, so that in the event of an explosion, the blast propagates vertically rather than horizontally.

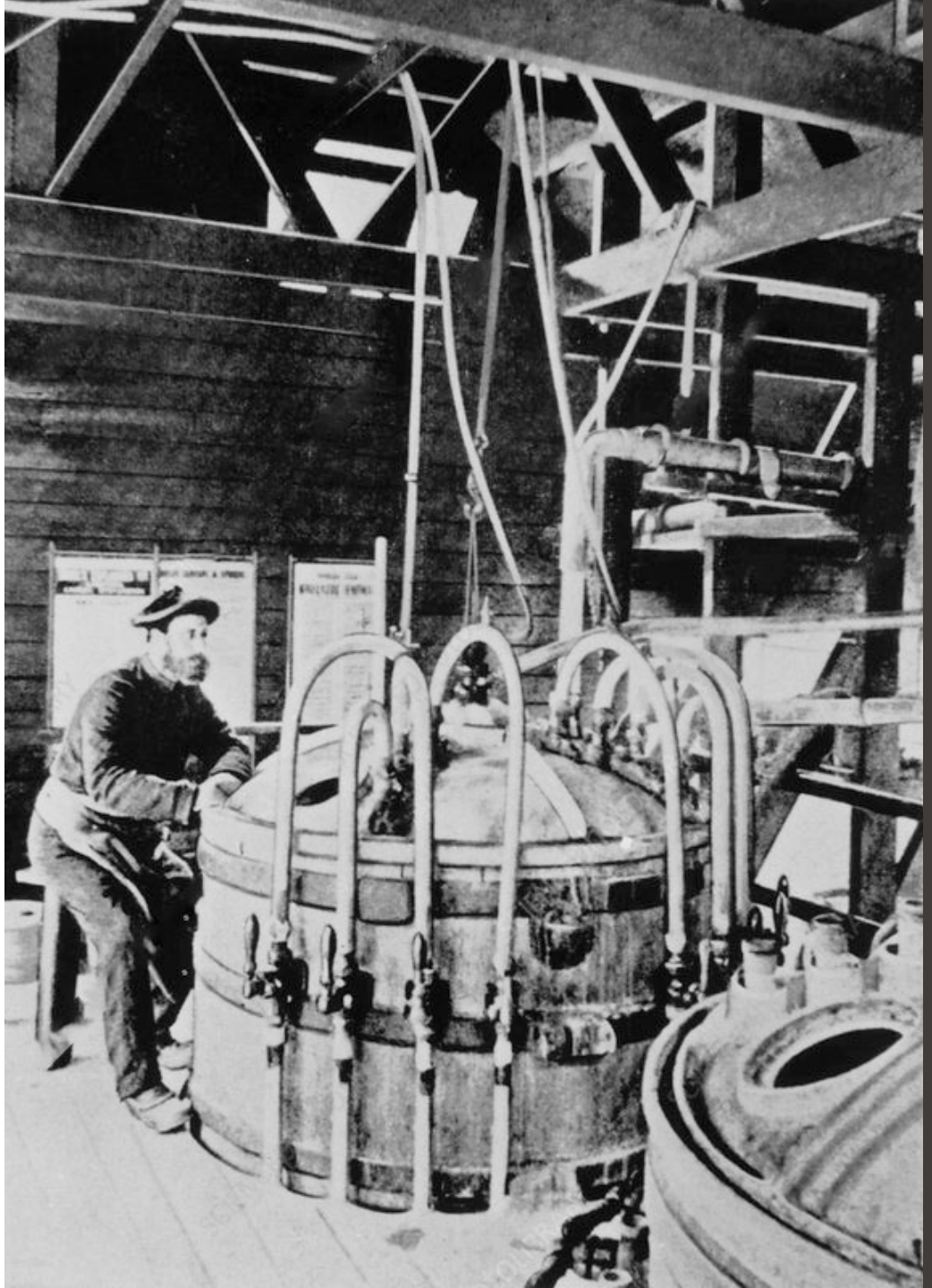
Source https://www.meisterdrucke.lu/fine-art-prints/Unbekannt/721342/Usine-de-traitement-de-la-nitroglyc%C3%A9rine,-usine-d39;explosifs,-Val-Bormida,-pr%C3%A8s-de-Cengio,-Italie,-1888.html



Source http://www.chm.bris.ac.uk/motm/nitroglycerine/nitroh.htm

Early safety measures

- An operator monitors the temperature for 8-10 hours and controls the feed to prevent overheating and explosion.
- The one-legged stool prevents the operator from becoming drowsy.



Source http://www.chm.bris.ac.uk/motm/nitroglycerine/nitroh.htm

Consider

- Operator stress
- Boredom (e.g. risk of falling asleep)

Which is more reliable ?

- Human control or technical control?
- Can automatic controls handle unexpected events?
- Are unsafe acts random ?

Source https://www.base.bund.de/EN/ns/ni-germany/npp/npp_node.html

Module 6.1:

The origin of safety culture

The example of NPP’s

Evolution of safety thinking

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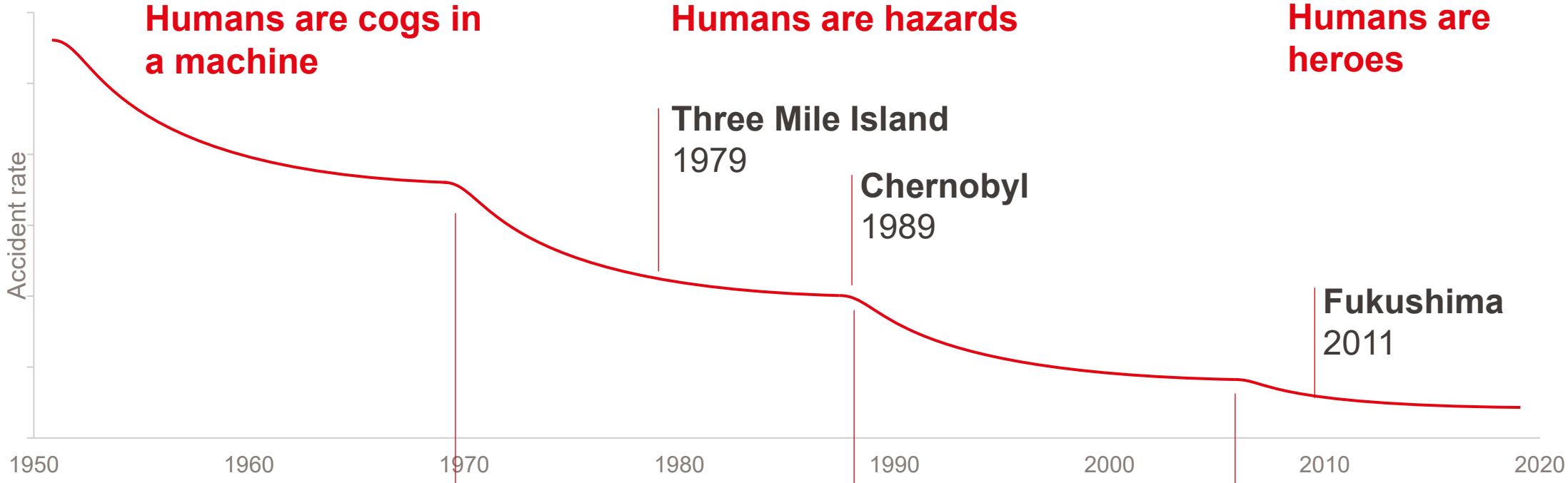

Technical era
Technical improvements
Reactive approach

Human era
Human factors
Human errors
Individual
Improvement of human-machine interface

Organizational era
Human factor
Systemic approach.
Integration of organisational factors

Global management era
System thinking, SMS
What is going right
Adaptative systems
Human sensor network
>>> **IA Era ?**

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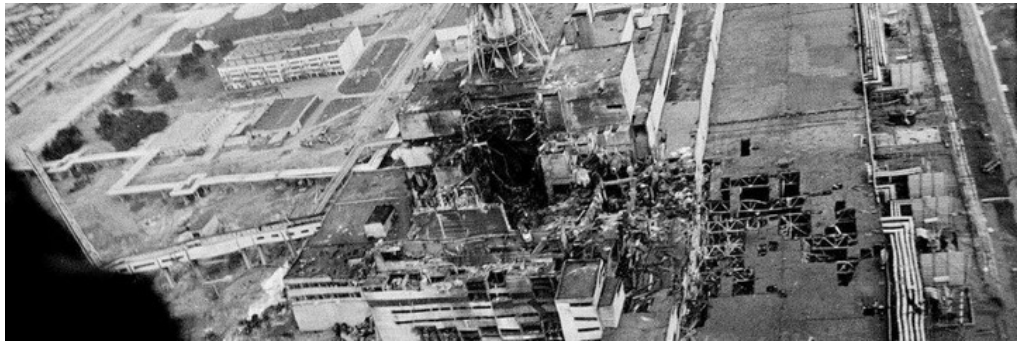
Historical examples: Major NPP accidents

Three Mile Island
1979, USA

The origins of the term safety culture

Chernobyl
1986, USSR



Fukushima
2011, Japan

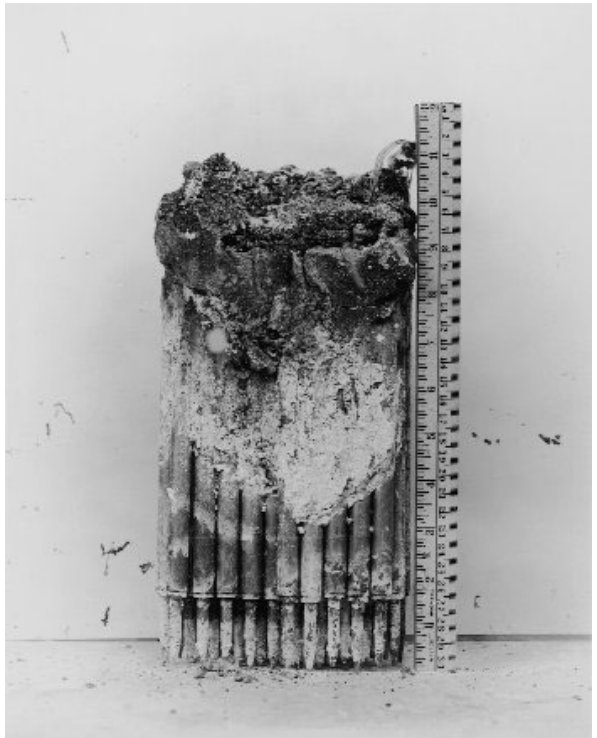
Source wikipedia

Experimental Breeder Reactor I (EBR-I)

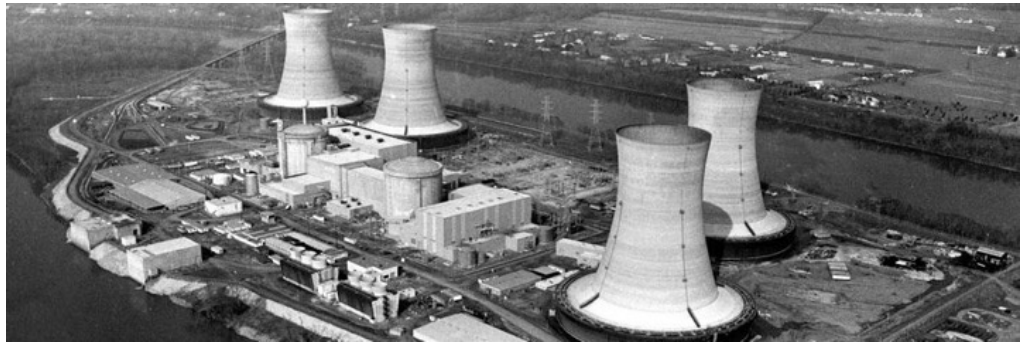
1951.12.20 One of the world's first electricity-generating nuclear power plants (Idaho, USA)

1955.11.29 partial meltdown during a coolant flow test.

The nuclear industry was still in its proof-of-concept stage!

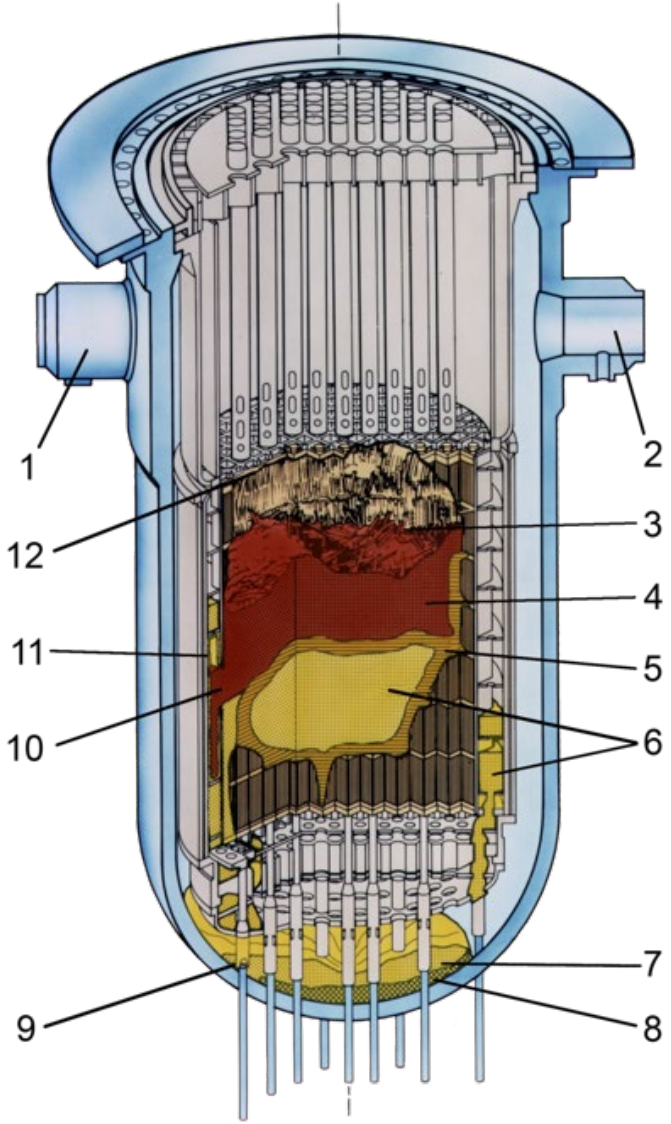


Three Mile Island



The most significant nuclear reactor accident in the U.S.A. (1979)

Led to a 34-year wait for a new nuclear power plant license.



partial meltdown of reactor 2

Source https://en.wikipedia.org/wiki/Three_Mile_Island_accident

Three Mile Island: The accident

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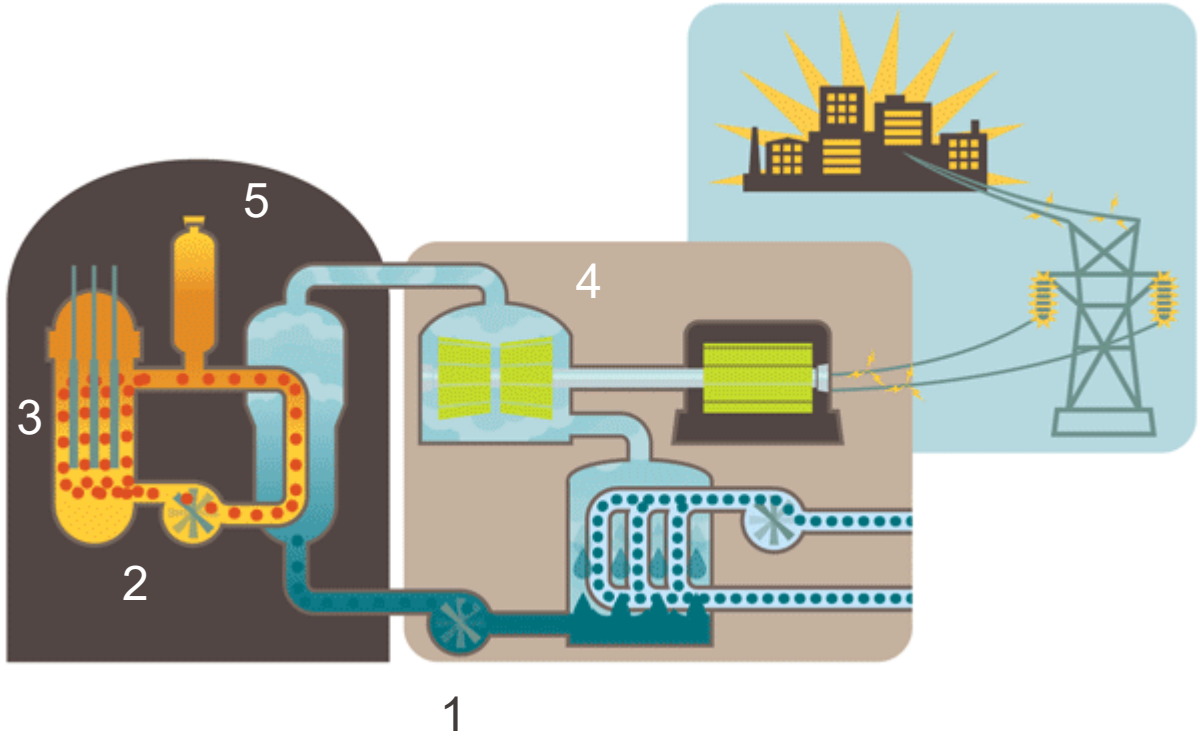

- The accident began about 4 a.m. on Wednesday, March 28, 1979, when the plant experienced a failure in the secondary, non-nuclear section of the plant (one of two reactors on the site).
- Either a mechanical or electrical failure prevented the main feedwater pumps—component (1) in the animated diagram—from sending water to the steam generators (2) that remove heat from the reactor core (3).
- This caused the plant's turbine-generator (4) and then the reactor itself to automatically shut down. Immediately, the pressure in the primary system (the nuclear piping portion of the plant shown in orange) began to increase.
- In order to control that pressure, the pilot-operated relief valve (5) opened. It was located at the top of the pressurizer (6). The valve should have closed when the pressure fell to proper levels, but it became stuck open.
- Instruments in the control room, however, indicated to the plant staff that the valve was closed. As a result, the plant staff was unaware that cooling water in the form of steam was pouring out of the stuck-open valve.
- As alarms rang and warning lights flashed, the operators did not realize that the plant was experiencing a loss-of-coolant accident.

Source https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

Human factors

- Before Three Mile Island, human factors were overlooked in nuclear plant operation.
- The prevailing belief was that safety systems alone could handle all safety-related events.
- The human role was underestimated, assuming humans would act unsafely.
- The accident resulted from a mix of factors:
  - Human error: misinterpretation, lack of training
  - Design flaws: indicators, control room
  - Technical problems: stuck valves

Human error caused by poor human machine interface

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The TMI control room four days after the accident (April 1, 1979)

It was already known that control rooms of this type could pose issues at some point …

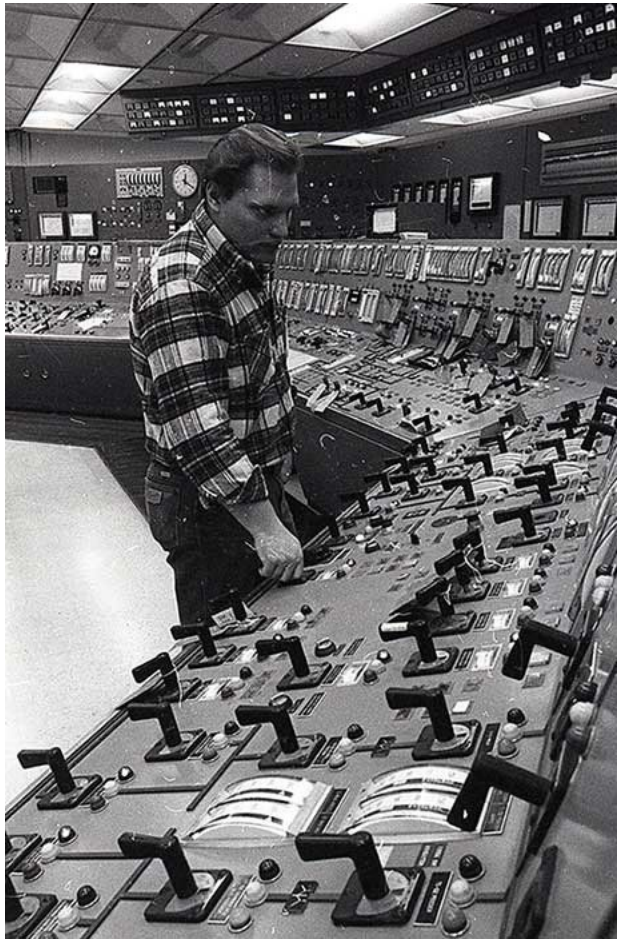
Visit from president Carter, accompanied by the Director of the U.S. Nuclear Agency Dr. Harold Dentonand the Pennsylvania Gov. Dick Thornburg.

Source https://uxdesign.cc/3-button-designs-from-3-different-decades-that-almost-results-in-catastrophe-9ac65498c9c4

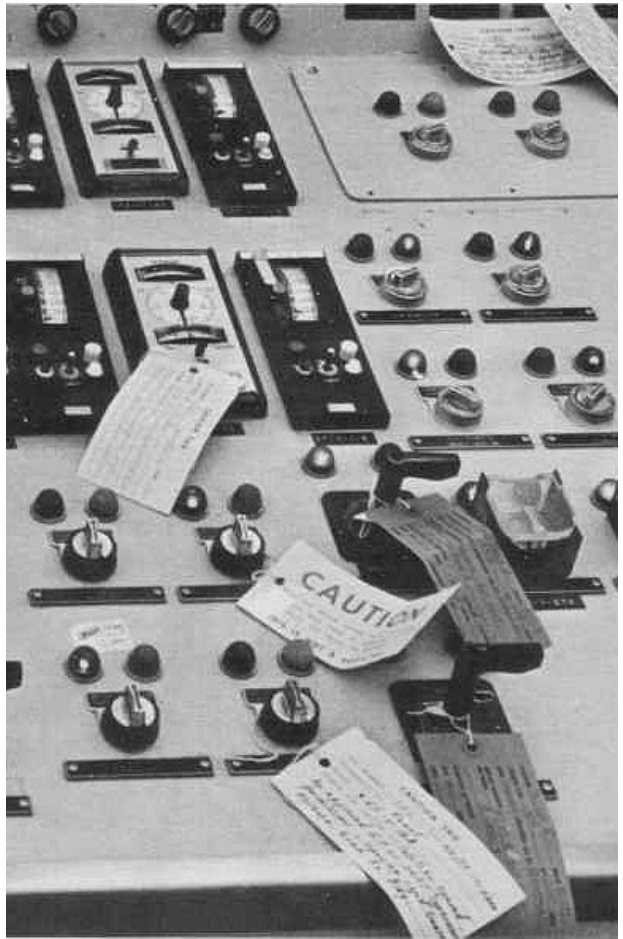
Three Miles Island conclusions

Post-TMI: Focus on “human error” - Including improvement of:

Training

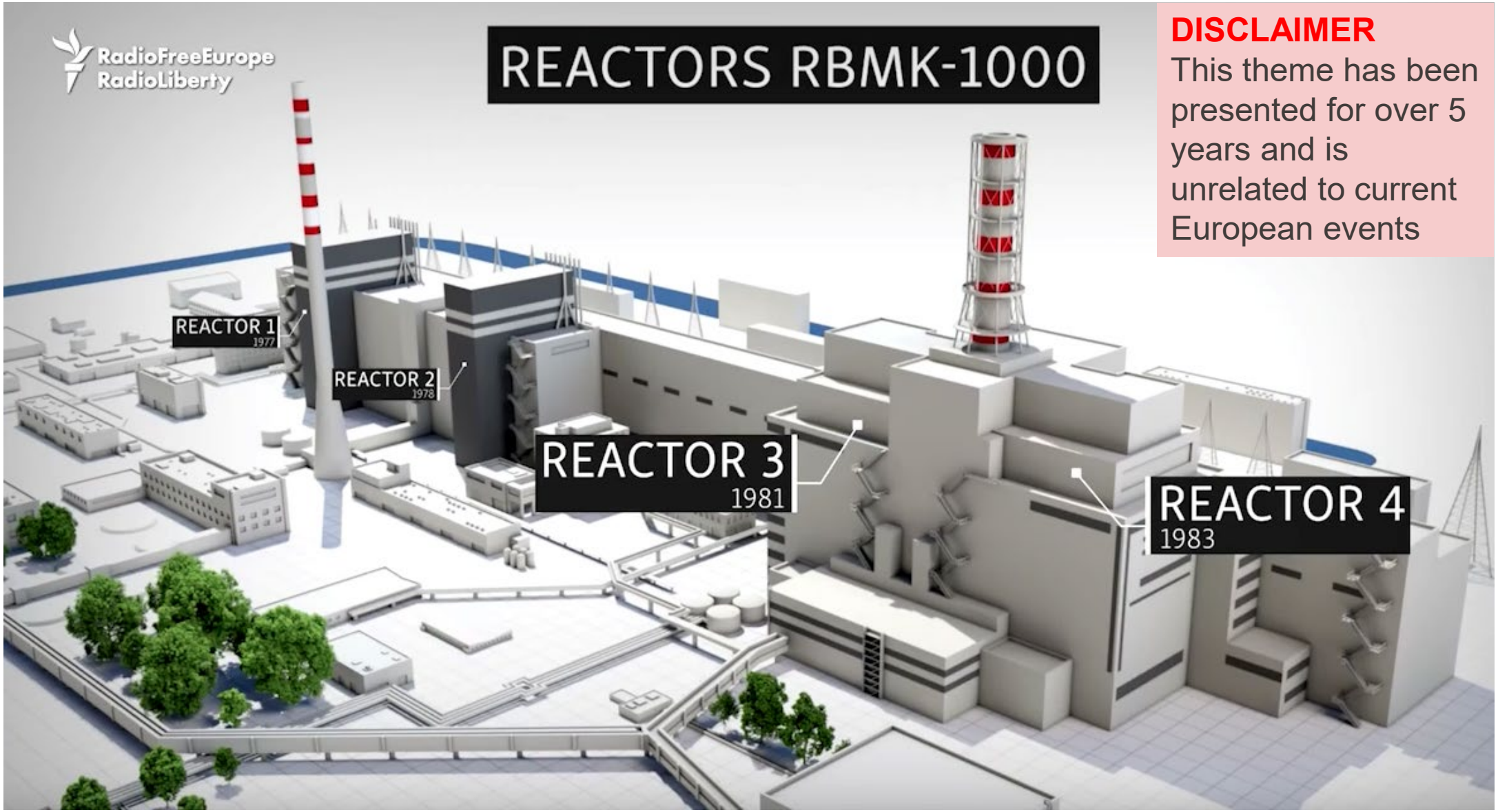


Man-machine interface



Procedures

Chernobyl Nuclear Power Plant Complex Units



DISCLAIMER
This theme has been presented for over 5 years and is unrelated to current European events

Source https://www.rferl.org

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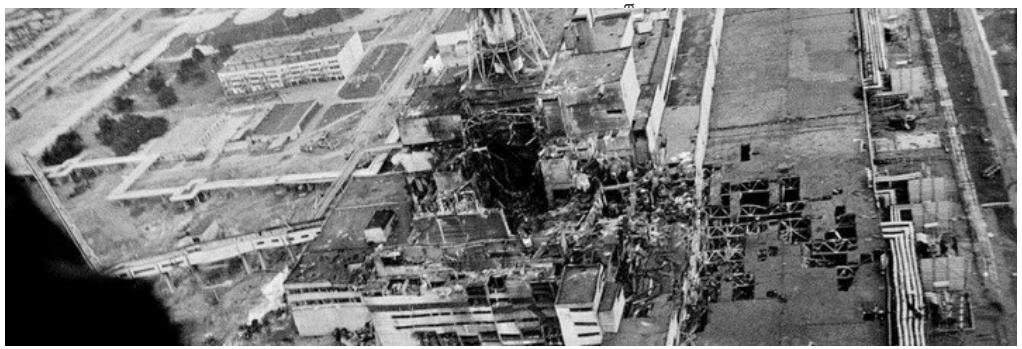
Chernobyl Disaster



26 April 1986: A test is conducted during a scheduled shutdown of reactor 4.

A few minutes after the test begins, the reactor experiences two explosions.

August 1986: The INSAG publishes their first report, INSAG-1.

- Blame is assigned to the plant operators.
- Deficiencies in the reactor design and operating regulations were mentioned only casually.
- The term “safety culture” is created.

1992 – INSAG-7: In the subsequent years and reports, blame was shifted away from the operators, and the concept of safety culture was further elaborated.

INSAG: International Nuclear Safety Advisory Group is requested by the International Atomic Energy Agency (IAEA).

The turbine test

- December 1983: Unit 4 is completed, and the standard 6-month test period is omitted. Power generation begins later in December, with some tests left unperformed.
  - The RBMK reactor relies on electricity to run crucial equipment (cooling pumps).
  - In the event of a shutdown, emergency generators take ~ 60 seconds to reach the required power level for operating the main cooling pump. This one-minute gap needed a solution.
  - Theory : using steam turbine momentum to generate sufficient electrical energy.
  - However, practical tests conducted in 1982, 1984, and 1985 proved unsuccessful.
- Modifications were made to various components, and it was determined that the turbine would be retested during a planned shutdown in 1986.

Planned procedure

- The test program was carried out **without** coordination with the chief designer of the reactor or the scientific manager, meaning the safety team was not involved.
  - Running the reactor at a low level between 700 – 800 MW.
  - Running the steam turbine at full speed.
  - Shutting down the steam supply to the turbine generator.
  - Recording the turbine's performance until the emergency generators came online and took over.

Events

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April 25th, 1986

- **1 PM:** Preparations for the test begin.
- **2 PM:** The Ukrainian electricity grid controller declares that all electricity for unit 4 is required, causing a 10-hour delay in the test.
- **4 PM:** The day shift departs, and the evening shift takes over.
- **11 PM**: Test preparations can resume.
- The evening shift is then replaced by the less experienced night shift. The procedures had only been explained to the day shift and the evening shift."

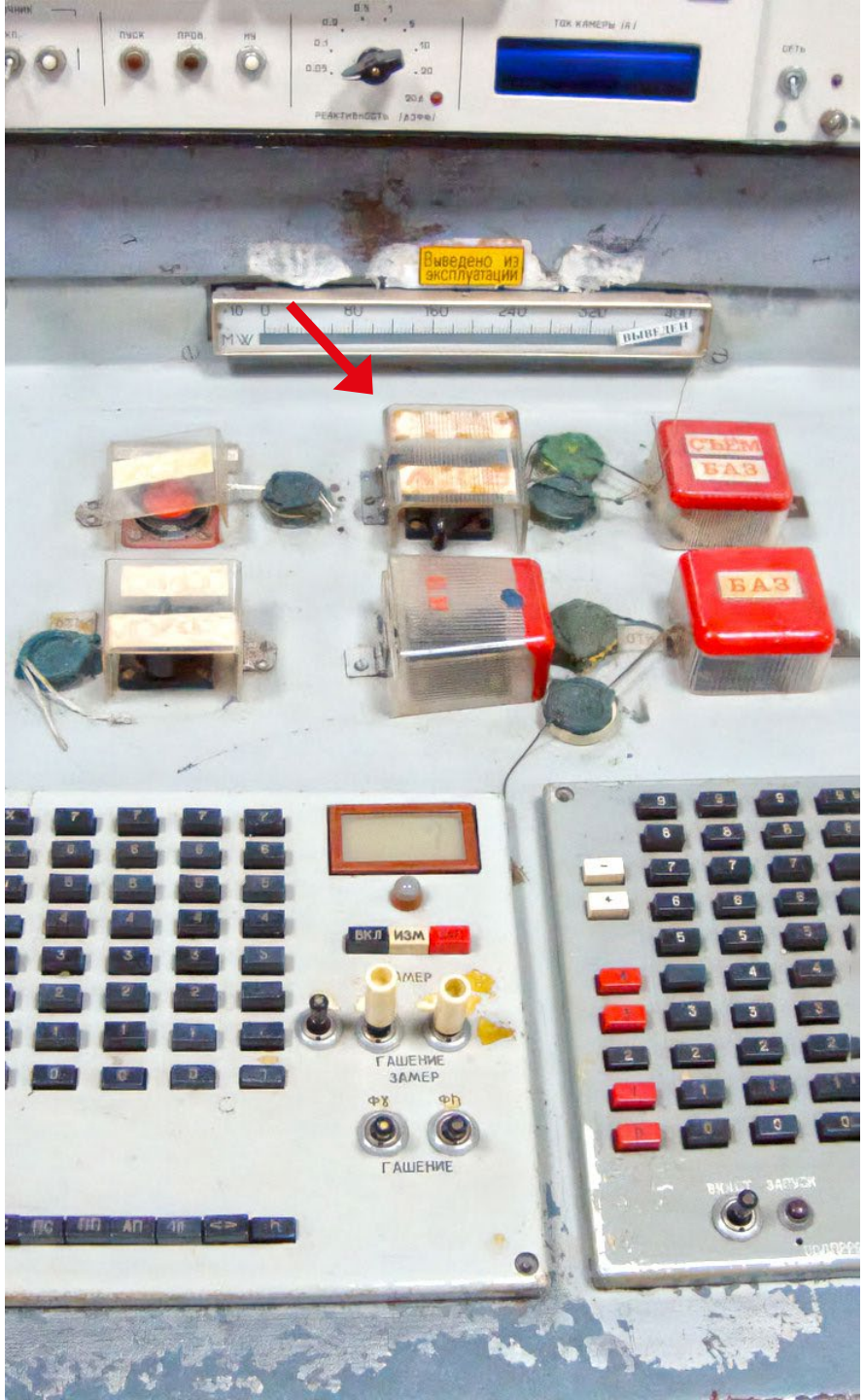
April 25th, 1986

00:28 AM: Stabilizing the plant becomes problematic, resulting in a capacity drop to 30 MW.

In the attempt to stabilize it, certain mistakes are made::

- ➞ Control rods are raised higher than regulations allow. This was not uncommon because:
  - The rules were often disregarded by everyone.
  - No prior incidents had occurred.
  - Operators were trained with the belief that a nuclear power plant could not explode.
- ➞ The plant's capacity falls below safety levels, indicating that testing should have been halted to allow operators to focus on stabilizing the plant.

Final chain reaction



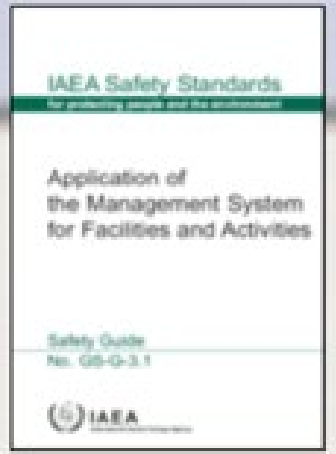
April 25th, 1986 continued:

- **1 AM:** the reactor is stabilized at 200 MW, **well bellow the 700 MW planned in the test procedure.** It is then decided to initiate the test.
- **1:23:04 AM:** Steam supply to the turbine is cut off. The decrease in turbine momentum causes a reduction in water flow, leading to increased steam formation.
- **1:23:40 AM:** The emergency shutdown is manually triggered (the reason is still unknown). Control rods are inserted, displacing water with their graphite tips before introducing the neutron-absorbing material, thereby increasing the reaction rate.
- **1:24 AM:** First explosion occurs (steam explosion).
- A second, more powerful explosion happens a few seconds after the first (hydrogen explosion).

A combination of latent problems

- **Isolation due to the Cold War**: Poor communication with the rest of the world.
- **Motivations**: The RBMK design was selected despite its known safety issues due to its cost-effectiveness and plutonium production capabilities.
- **Flawed design** : No containment structure, a positive void coefficient, and problematic rod design.
- **Safety was not a primary concern**: Strong pressure from higher authorities to deliver results. Even when the test should have been stopped, operators were compelled to continue under pressure.
- **Questioning was not allowed**: Announcing problems was frowned upon, resulting in the repetition of unsafe practices until catastrophic events unfolded. Disregarding safety rules became commonplace.
- **Failure to learn from previous accidents**: Accidents had happened before with the RBMK.
- **Lack of accountability** within the regulatory bodies under the Soviet structure.
- Operators **lacked sufficient training**, the ability to question, and a comprehensive understanding of the system.

IAEA Safety culture characteristics and attributes (GS-G-3.1)



Safety is a clearly recognized value

Leadership for safety is clear

Safety Culture Characteristics

Accountability for safety is clear

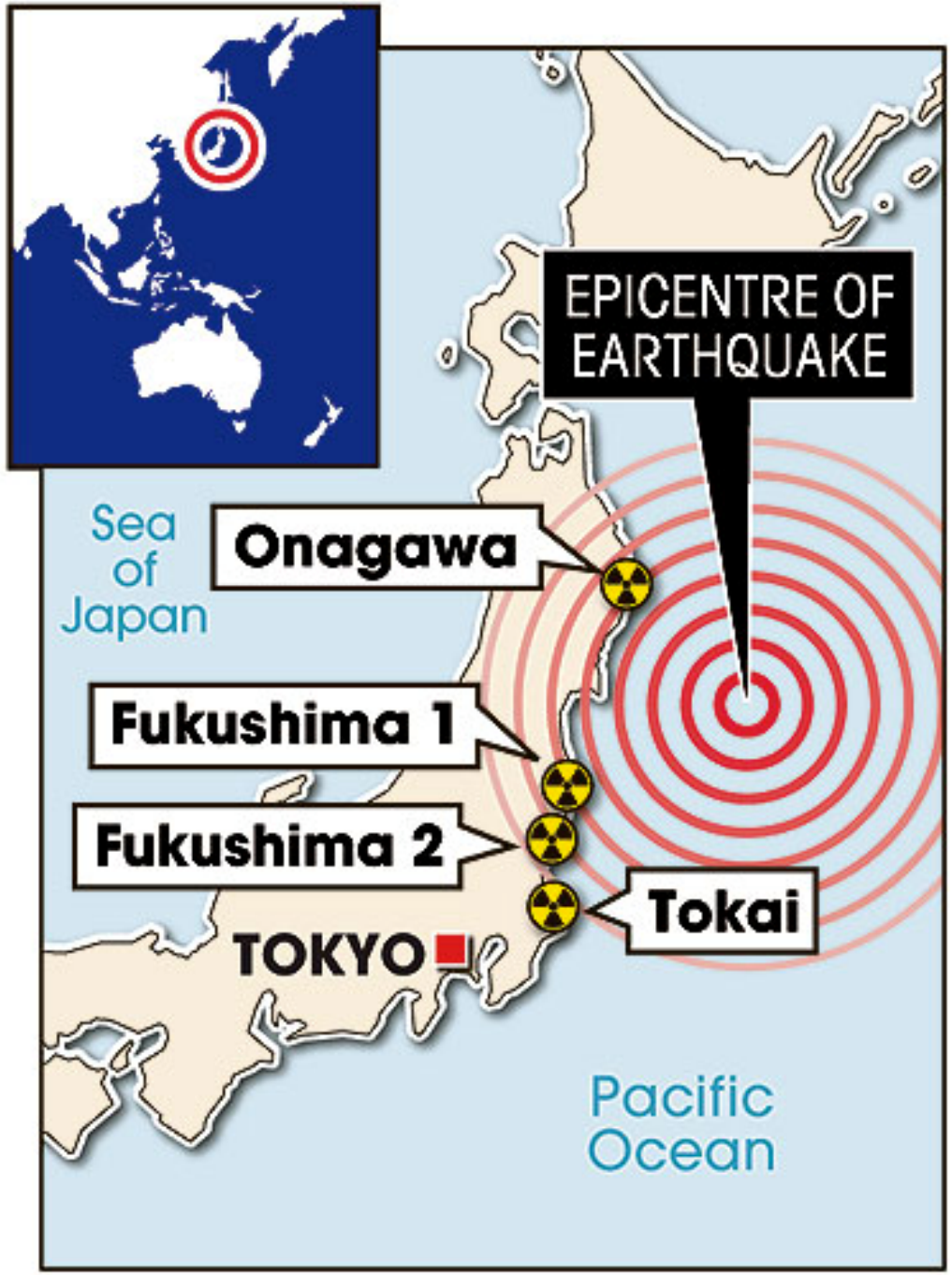
Safety is integrated into all activities

Safety is learning driven

IAEA

Fukushima vs Onagawa

- Fukushima No.1 experienced a catastrophic meltdown and radiation release.
- Fukushima No.2, however, witnessed heroic efforts by operators and improvisation that led to the successful cold shutdown of the four operating reactors.
- Onagawa:
  - 60 km closer to the earthquake's epicenter than Fukushima No.1.
  - The tsunami reached 14.3 meters, surpassing the 13.1 meters observed at Fukushima No.1.



Source: https://bravenewclimate.com/2011/04/07/lessons-nuclear-quake-tsunami/

Some differences…
Fukushima: Tokyo Electric Power Co.'s - TEPCO
Onagawa: Tohoku Electric Power Co.'s.

Examples:

- TEPCO, in an effort to streamline equipment transport and cut construction expenses, removed 25 meters from the original **35-meter natural dam** at the Fukushima No. 1 plant, ultimately constructing its reactor buildings at a **lower elevation of 10 meters**.
- In contrast, Tohoku Electric, when building Onagawa, opted for a higher elevation compared to TEPCO's Fukushima reactor building.
- Tohoku Electric conducted thorough studies, simulations, and learned from past earthquakes like the one in Chile to improve its countermeasures. In contrast, TEPCO was slower to respond, including delaying alternative scientific studies and lobbying.

Fukushima: A Brief Overview of the Accident

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- In the wake of a powerful earthquake, the nuclear power plant's safety systems triggered an automatic shutdown of the nuclear reactors. Emergency diesel generators were activated to keep the coolant around the reactor cores, which remained extremely hot
- However, a massive tsunami, towering more than 14 meters, struck Fukushima shortly after, breaching the defensive dam, flooding the facility, and disabling the emergency generators.
- Despite frantic efforts by workers to restore power, in the ensuing days, the nuclear fuel in three of the reactors overheated and partially melted, leading to what is known as a nuclear meltdown.
- The plant also experienced several chemical explosions that inflicted severe damage to its buildings. Consequently, radioactive materials started to leak into the atmosphere and the Pacific Ocean, necessitating evacuations and the establishment of an expanding exclusion zone.

Source: https://www.bbc.com/news/world-asia-56252695

Conclusion : Considering the three factors

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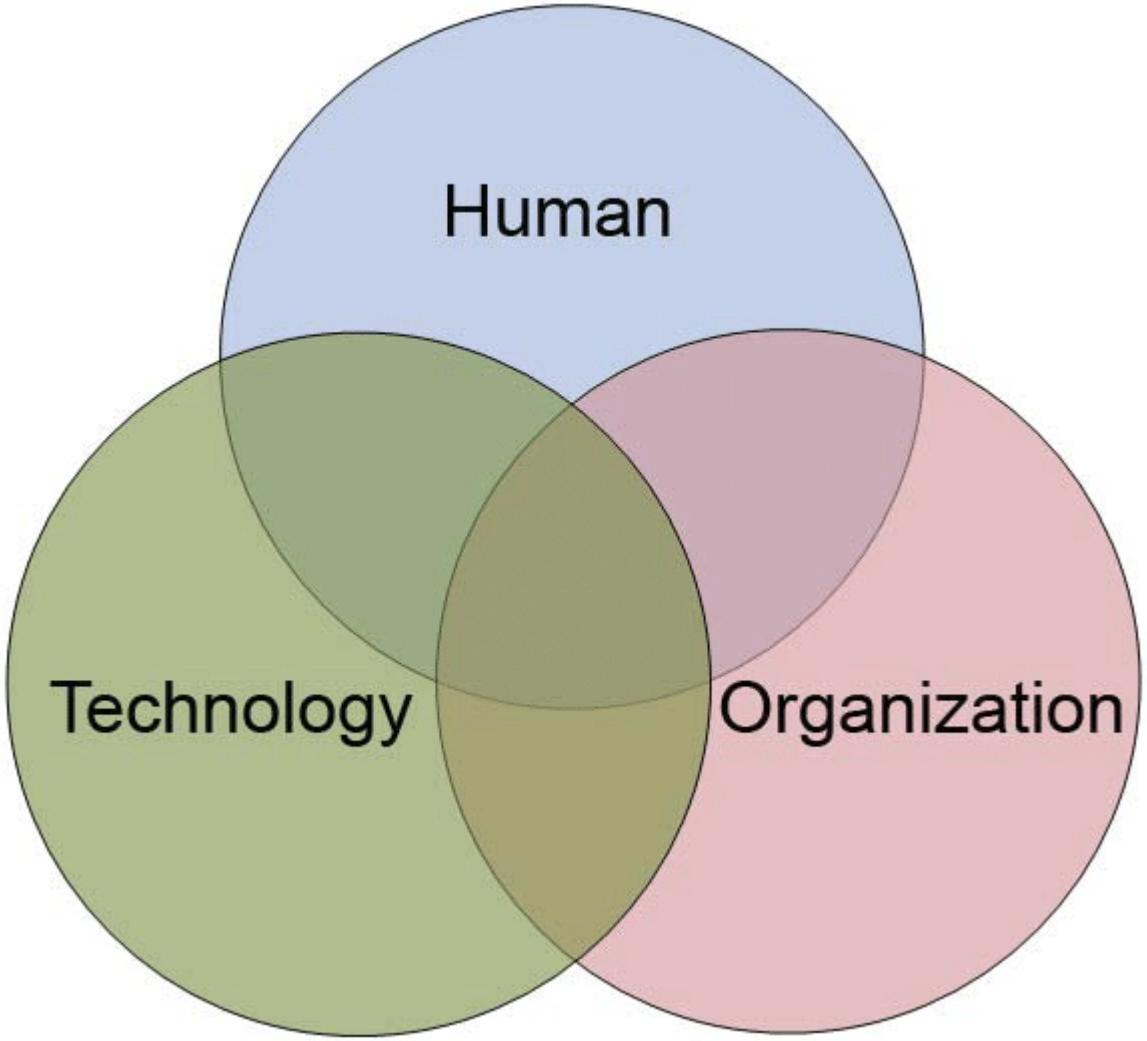
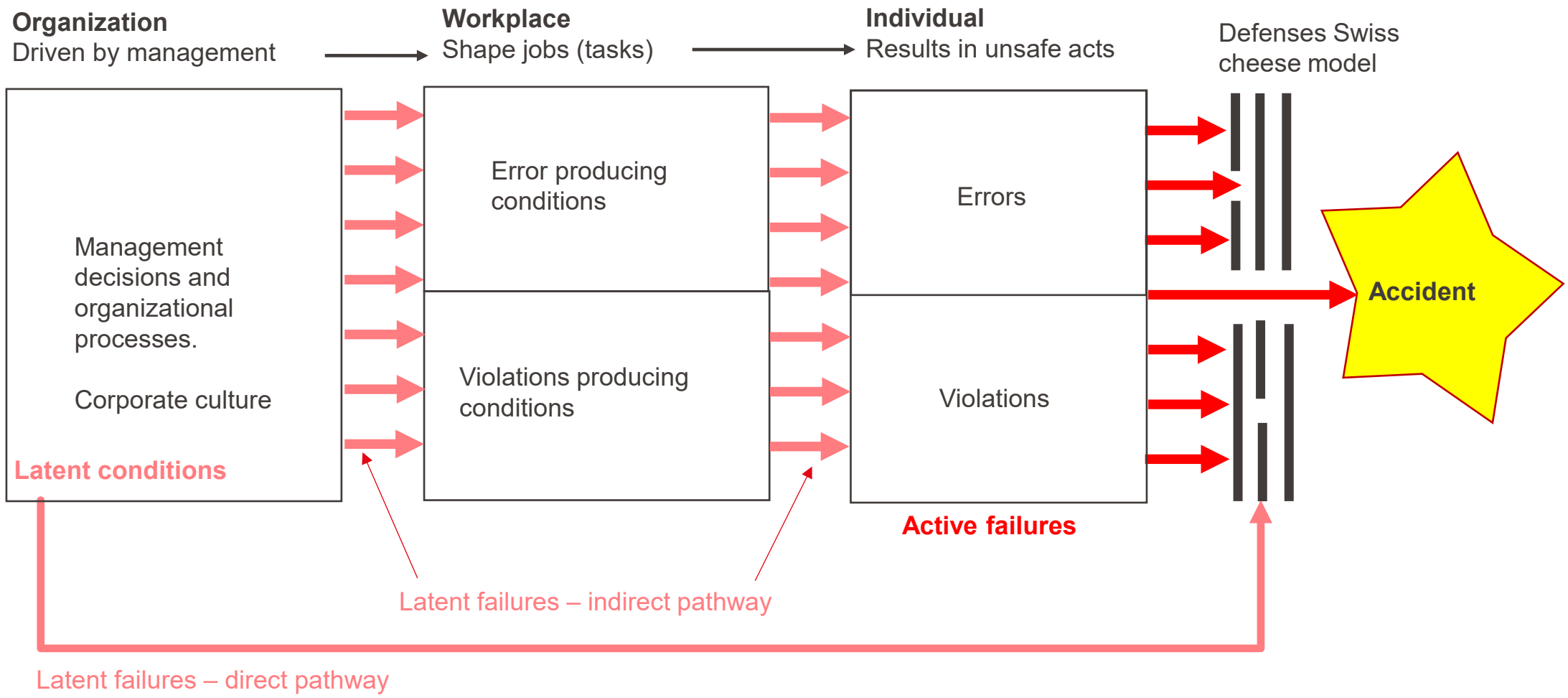
The human and organizational factors must be understood and managed with **as much rigor as the technical aspect of safety**.



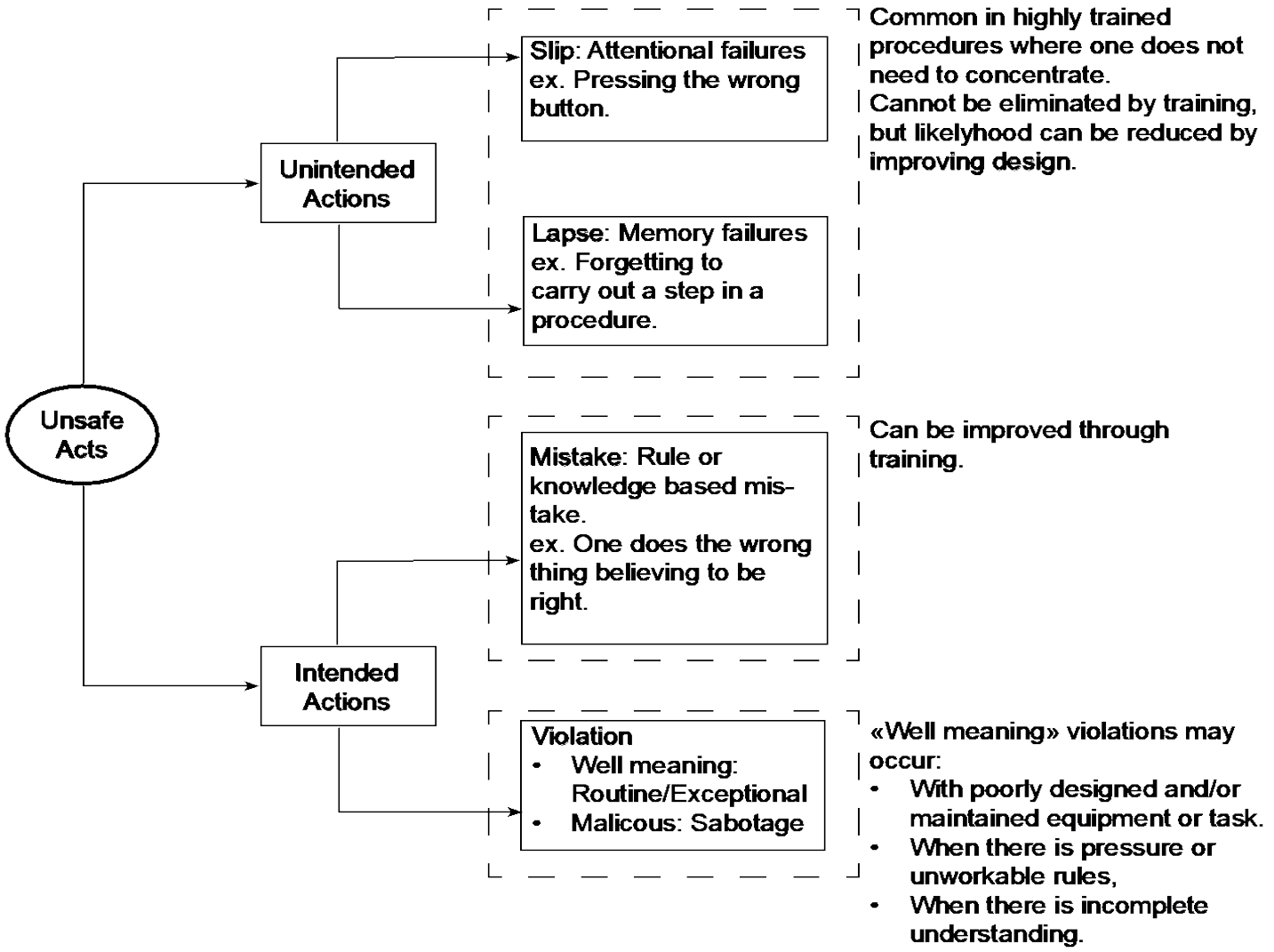
Module 6.2 :

Human and Organizational factors

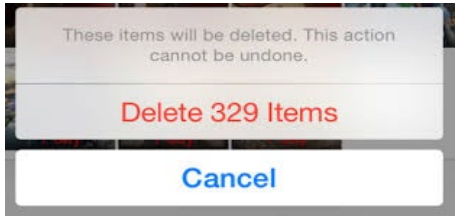
Reason's model of accident causation



Human errors / violations: Understanding unsafe acts



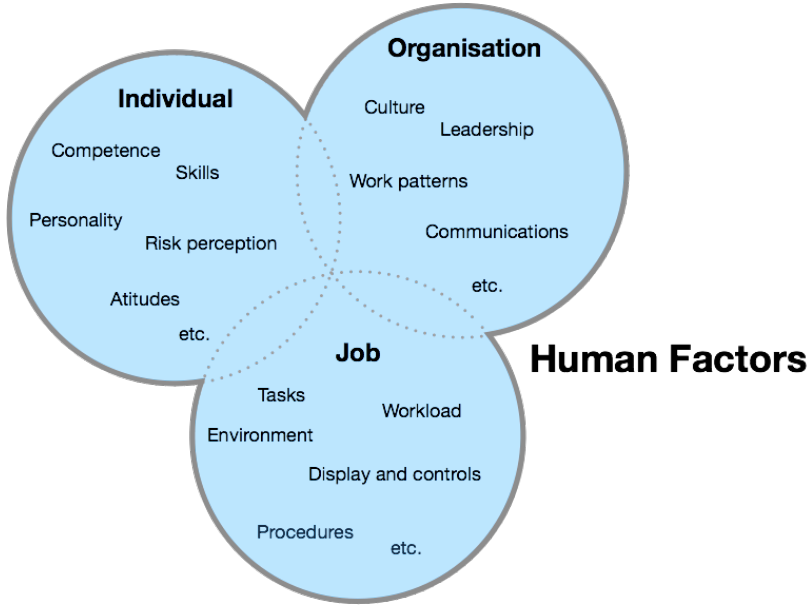
Human errors / violations



Human Cognitive Reliability (HCR) decision tree and possible error modes (Hollnagel, 1998)

Human factors

- Originally, human factors was defined as the scientific study of human-machine interaction.
- Over time, this definition has evolved as our knowledge has expanded, and human factors (HF) has transformed into a multi-disciplinary field, incorporating disciplines like cognitive psychology and engineering.
- Subsequently, the definition was further expanded to encompass other factors that influence health and safety.



Source: Gordon, Rachael PE. "The contribution of human factors to accidents in the offshore oil industry. " Reliability Engineering & System Safety 61.1-2 (1998): 95-108.

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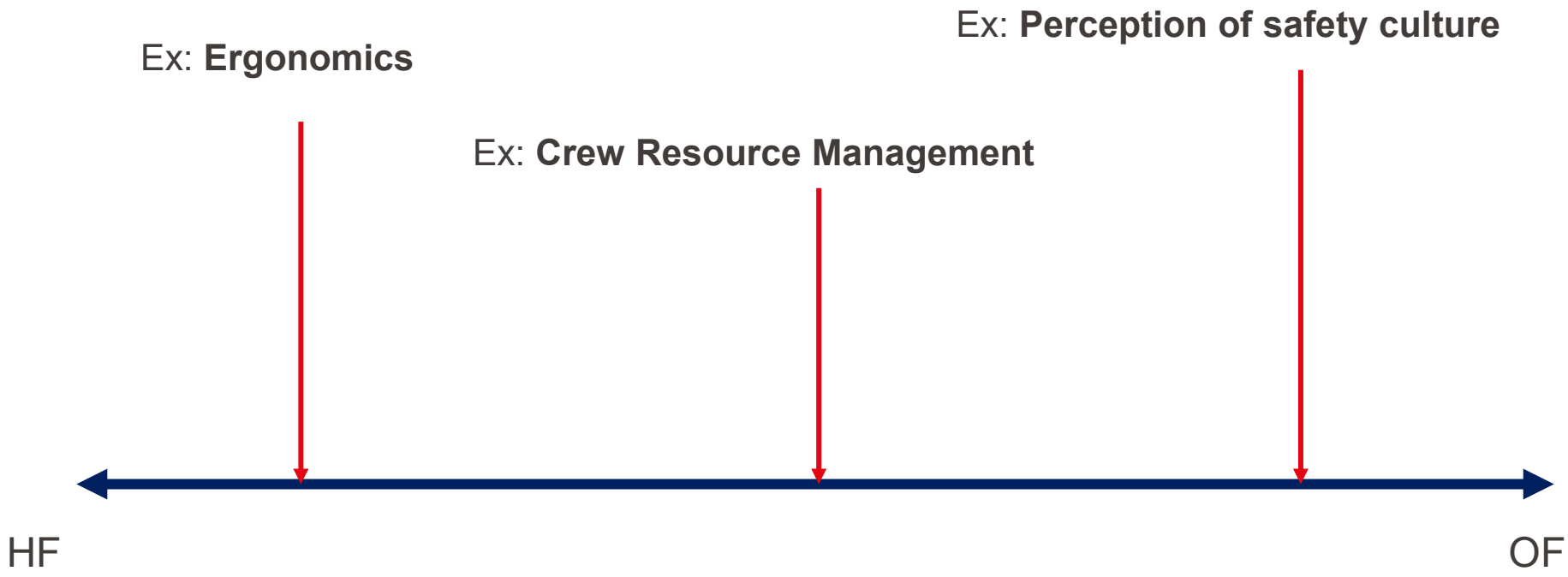
From Human Factor to Organization Factor



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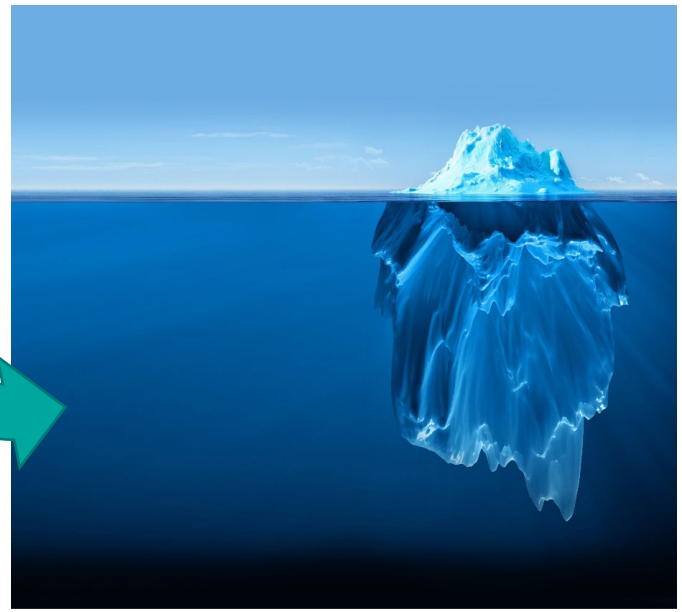
Safety I vs Safety II

Safety II

- Proactive approach
- Concentrates on things that go right
- Prioritizes variability in human performance
- Shares responsibility for system outcomes

Safety I

- Reactive approach
- Centers on things that go wrong
- Highlights human error
- Tends to assign blame to frontline staff



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Barriers and bias block effective communication

These include filtering, selective perception, information overload, emotional disconnects, lack of source familiarity or credibility, workplace gossip, semantics, gender differences, differences in meaning between Sender and Receiver, and biased language.

BARRIERS

Physical
Mental

Bias

Influences

Communication – Differences in meaning

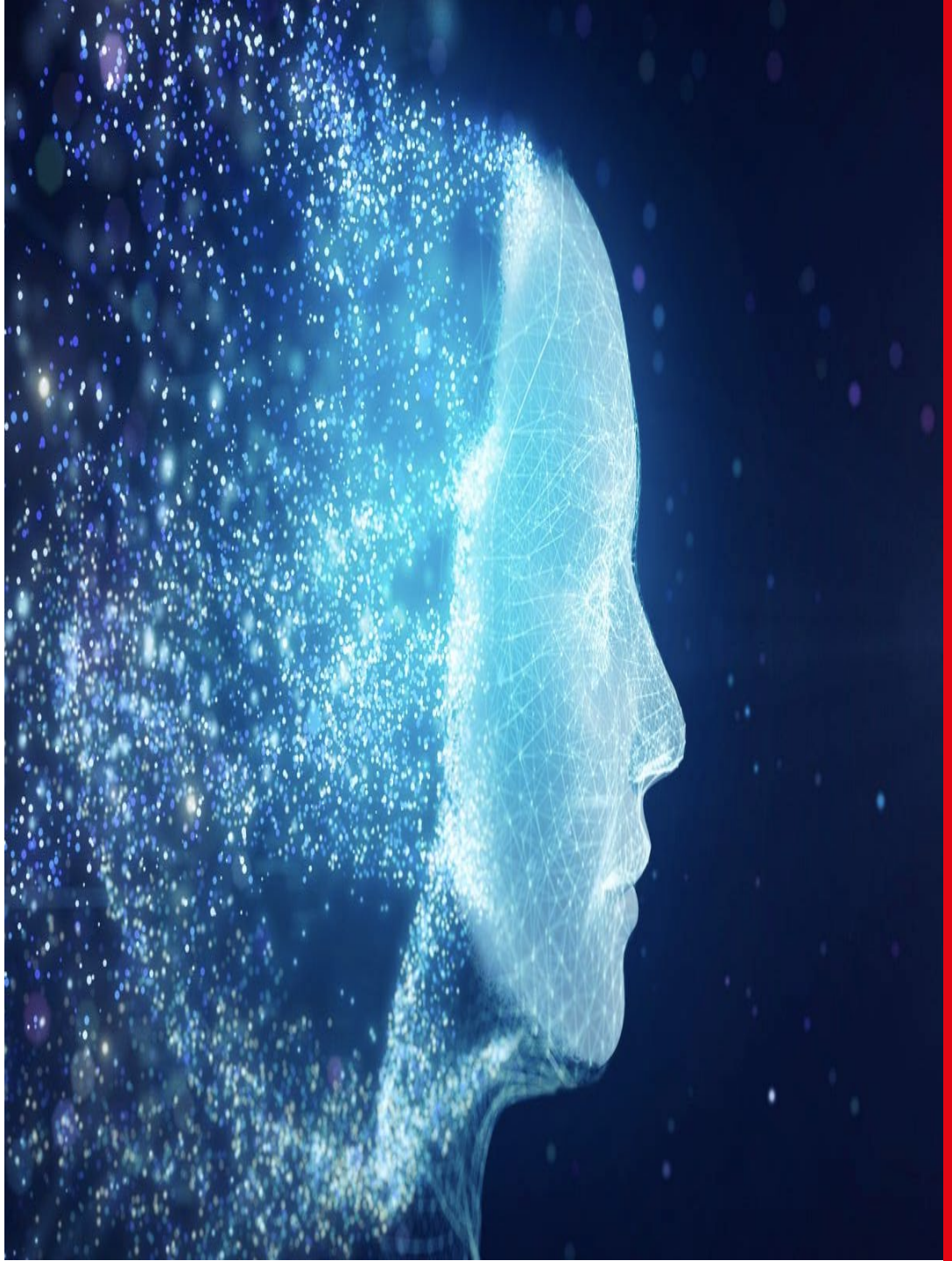
Examples of Gestures from Around the Globe

"V" for victory. Use this gesture with caution! While in North America it signs victory or peace, in England and Australia it means something closer to "take this!"

The *"thumbs up"* means one in Germany, five in Japan, but a good job in North America. This can lead to confusion

The "OK" gesture. While in North America it means things are going well, in France it means a person is thought to be worthless, in Japan it refers to money, and in Brazil, Russia, and Germany it means something really not appropriate for the workplace

"Hook 'em horns." This University of Texas rallying call looks like the horns of a bull. However, in Italy it means you are being tricked, while in Brazil and Venezuela it means you are warding off evil.



https://www.forbes.com/sites/forbesbusinesscouncil/2021/04/14/understanding-what-artificial-intelligence-is-and-what-its-not/

Module 6.3 :

AI and its Effect on Workplace Safety

Definition AI, ML and IoT

- AI, or Artificial Intelligence, is the development of computer systems that can perform tasks typically requiring human intelligence, such as visual perception, speech recognition, decision-making, and problem-solving. The quality of each AI model depends on the machine learning capabilities on which it is based.
- Machine learning focuses on the development of algorithms and models that enable computers to improve their performance on a task through experience and data analysis.
- Once the ML system has identified the problems, AI can propose solutions to achieve the best results.
- It mimics human behavior, but it is far more capable of handling multiple data and finding solutions to seemingly impossible challenges.
- In the area of workplace safety, AI can help reduce risks and create a safer working environment by using the Internet of Things (IoT). *IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction*.

Thierry Meyer

Benefits of Using AI to Improve Workplace Safety

1. Minimizing Human Error (reducing fatigue and stress)
2. Automating Hazardous Tasks (robotic production in dangerous environments)
3. Employee Monitoring (including vital sign monitoring and alerting in hazardous settings)
4. Harassment Detection (alerting in cases of workplace harassment or poor communication)
5. Equipment Maintenance (identifying faulty machines)
6. Crime Detection and Prevention (proactive detection methods)

AI risks and challenges to workers' safety and health

1. Work Intensity (heightened productivity and high-speed work)
2. Reduced Control and Autonomy (potential AI takeover)
3. Dehumanization of Workers (forcing machine-like behavior)
4. 'Datafication' of Workers (viewing workers as digital data producers)
5. Discrimination and Use of Private Data (intrusive surveillance and automated decisions)
6. Performance Monitoring Impact (possible neglect of breaks and social interaction)
7. Worker Evaluation Systems (potential for penalization)
8. Risky Behavior (AI-induced pressure for speed may lead to unsafe actions)
9. Lack of Transparency and Trust (often opaque AI implementation in organizations).

Source: Artificial intelligence for worker management: implications for occupational safety and health Report European Agency for Safety and Health at Work

AI and safety/risk management -1- Pros

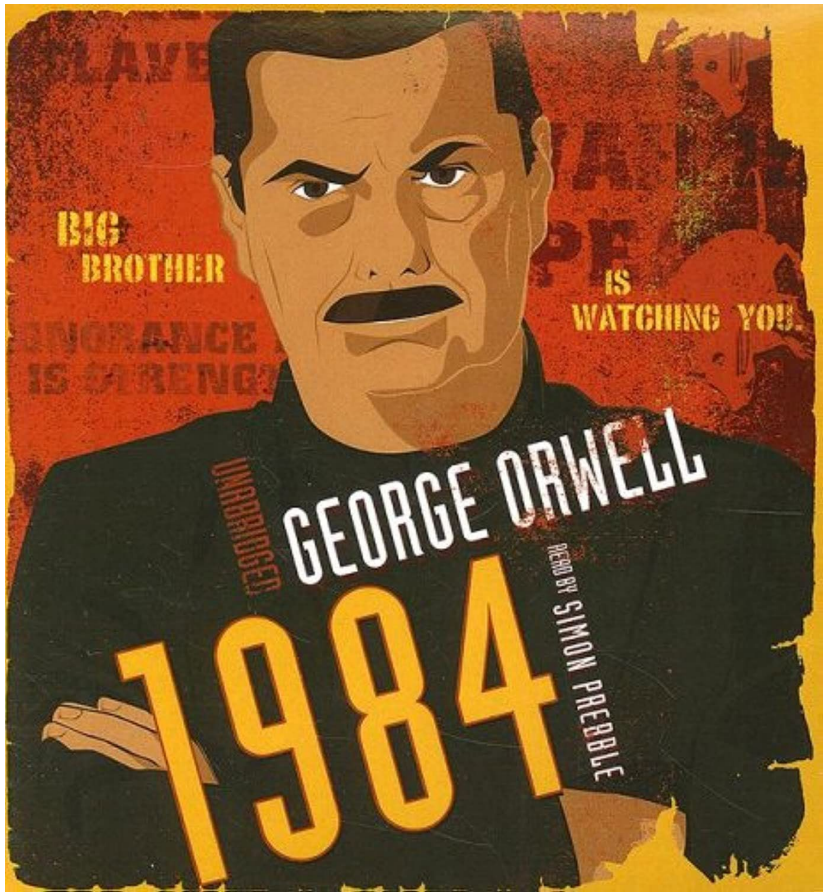
1. Predictive Analytics: AI can analyze safety data to predict and prevent accidents.
2. Risk Assessment: AI can assess data to identify potential safety risks.
3. Autonomous Systems: AI enhances safety in high-risk industries by aiding autonomous systems.
4. Training and Simulation: AI tools assist employees in safety skill practice and improvement identification.

AI and safety management -2- Cons

AI is not a panacea for safety management; challenges like bias and data privacy risks need cautious handling.

Organizations must devise a holistic AI strategy that includes measures to address these concerns, promoting responsible and ethical AI use.

What's your opinion ?



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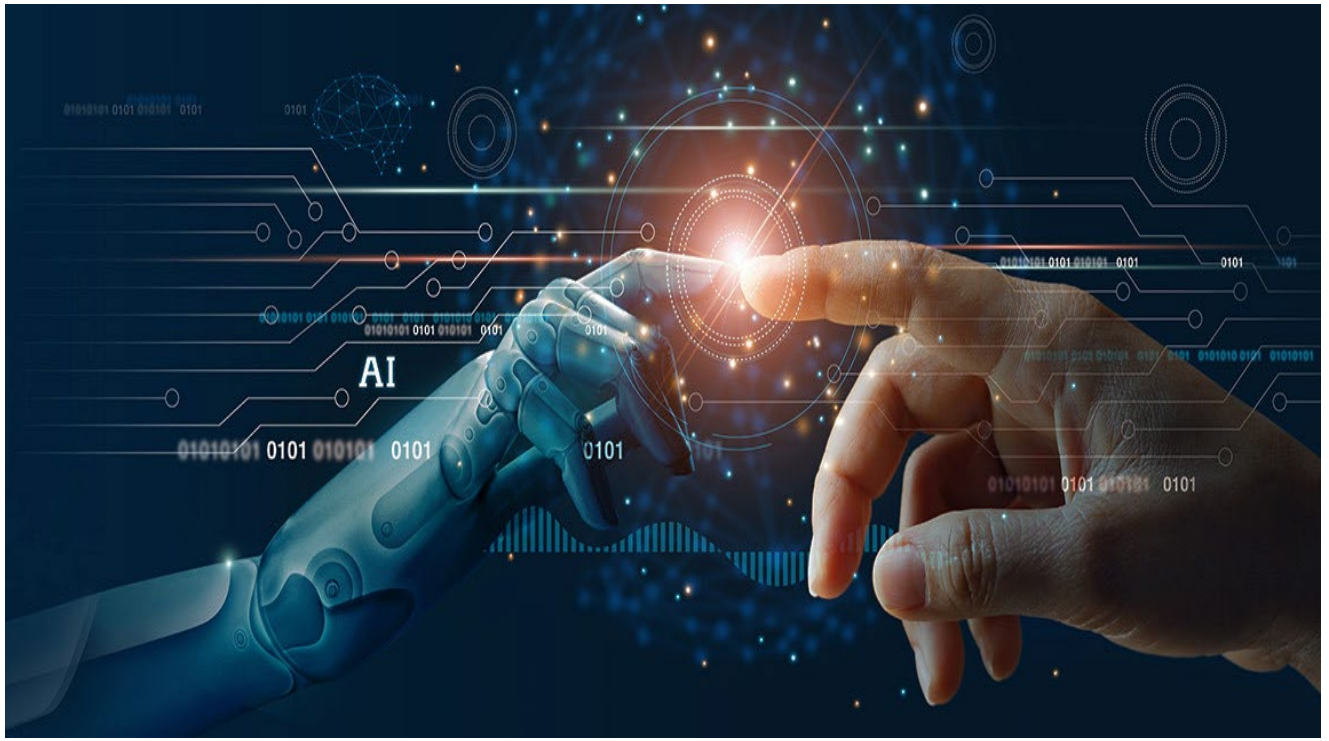

Source: https://www.softwareone.com/en-be/blog/articles/2021/04/05/implementing-artificial-intelligence-part-1

Risk management or safety culture?

Time: 52``