

NUCLEAR DISASTER

MAN-MADE AND NATURAL NUCLEAR DISASTERS, MANAGEMENT
AND MITIGATION.

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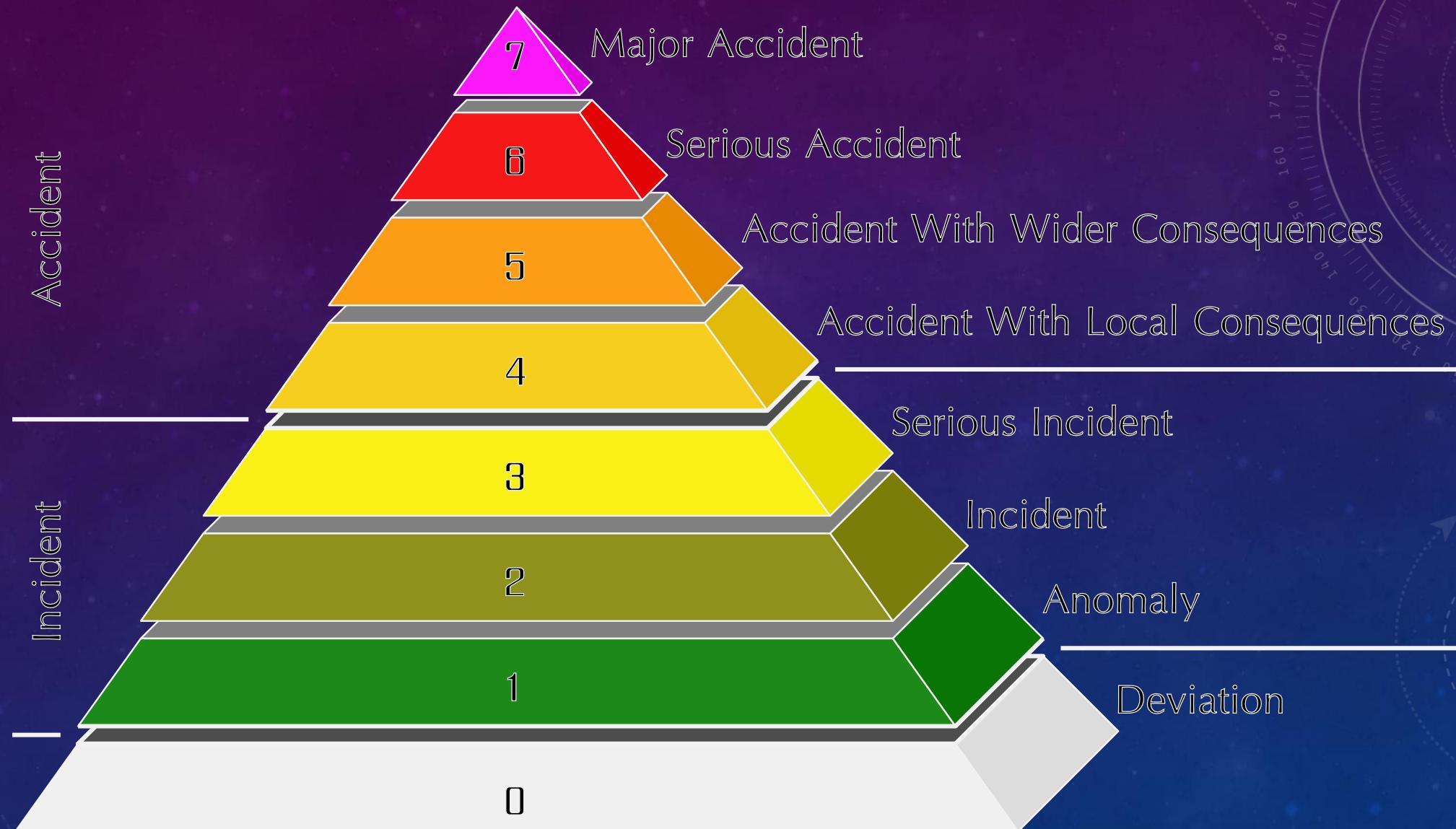
DEPARTMENT OF MATHEMATICS

THE STORY OF FUKUSHIMA-DAIICHI,

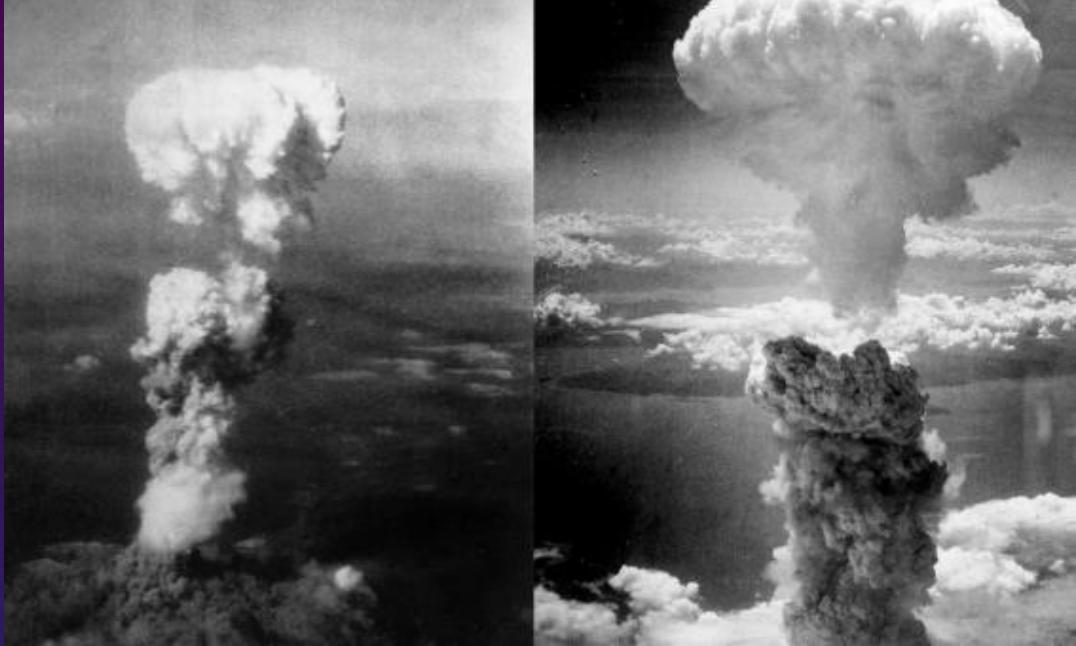


Due to the damage done by a tsunami, a nuclear accident occurred in *Fukushima Daiichi Nuclear Power Plant* in Ōkuma, Fukushima, Japan.

- The accident was classified INES 7 (International Nuclear Event scale) as a “Major accident”.
- The town of Okuma is still deserted and will be uninhabitable by humans for at least 50-100 years

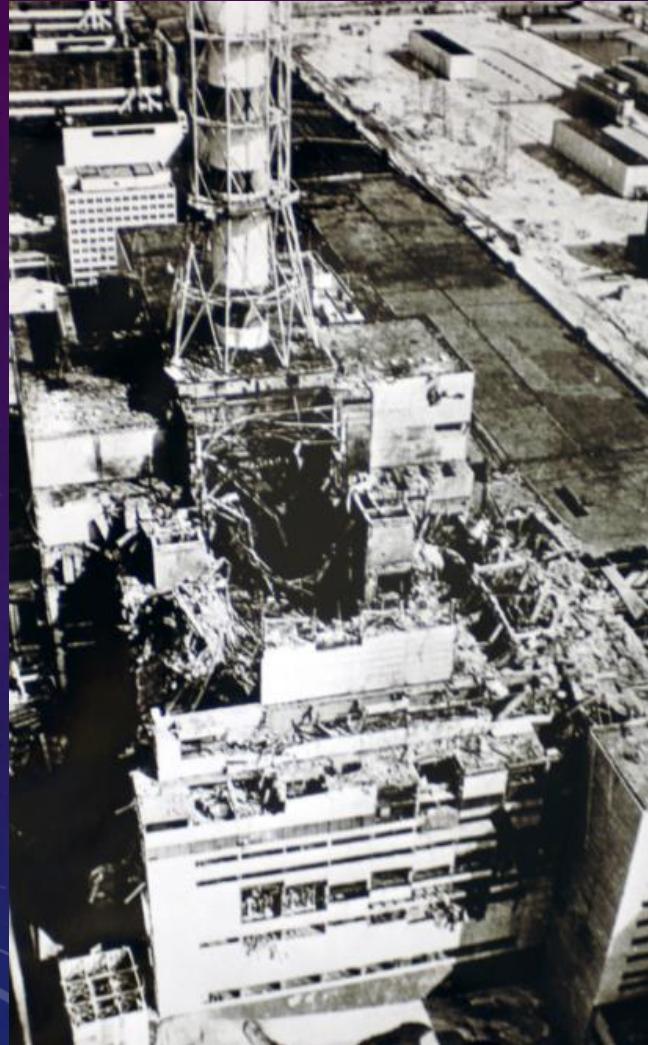


THE STORY OF HIROSHIMA- NAGASAKI



The infamous nuclear bombing incident from the second world war still has crippling effects on the population of Japan. Following immediate obliteration of the city, **cancer rates** and **birth defects** rose significantly in the medium-long term.

CHERNOBYL

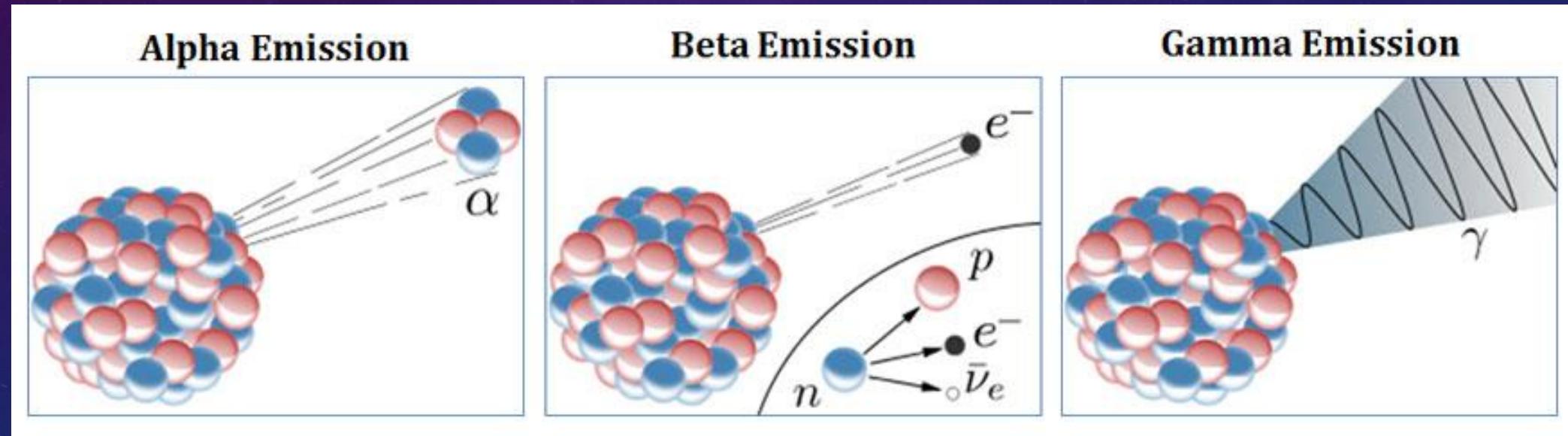


By far the most harrowing nuclear disaster humanity has seen. Although it was an accident, radiation hazards have been realised first hand.

- Steep cancer rate increases post the disaster (mainly thyroid cancer and leukaemia)
- Death toll of more than 5000 + (official death toll by the USSR was 31 due to Acute radiation syndrome)
- Chernobyl remains uninhabitable for at least 20,000 years
- Losses by the Ukrainian government are reported at 235 billion USD (Ukraine's GDP in 2019 was 153 billion USD)

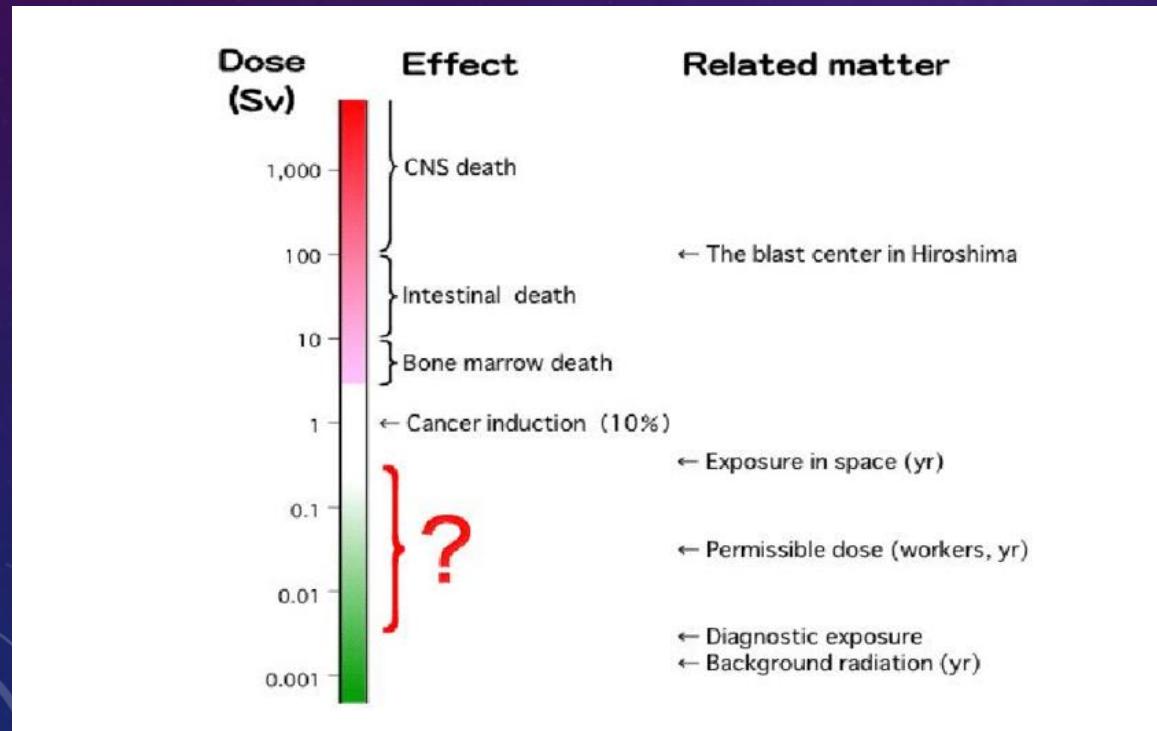
WHAT IS RADIATION?

- High energy photons constitute “Radiation” or “Nuclear radiation”
- γ rays, , X rays, α rays and β rays constitute nuclear radiation



WHY IS RADIATION DANGEROUS?

- Exposure is decided in terms of Sv (sieverts). Normally the yearly background radiation exposure is 3.65 mSv (0.00356 Sv)
- However in nuclear disaster events, the radiation dose exceeds the limit to more than 1 Sv. Depending on the dose, the effects range from mild cellular damage to death by ARS



- Exposure to > 1000 Sv of radiation in one dose will result in death > 50 percent of the times. This percentage increases with increase in dose
- The effects due to radiation are classified into Immediate and Stochastic effects. **Immediate effects** are ones which can be immediately seen (death, hair loss) while **Stochastic effects** take more time and may develop or not (leukaemia, aplastic anaemia)

ACUTE RADIATION SYNDROME

Has 4 phases:

Prodromal stage: Following immediate exposure, the subject may have Vomiting, diarrhoea, or a fever

Latent stage: The patient appears to be recovering and even healthy for a short time

Sustained illness stage: The cellular damage to the DNA begins to manifest in the body and causes high fever, skin lesions, electrolyte disturbance and many other serious symptoms

Death/Recovery

The following link explains it well: [Acute radiation syndrome - Wikipedia](#)

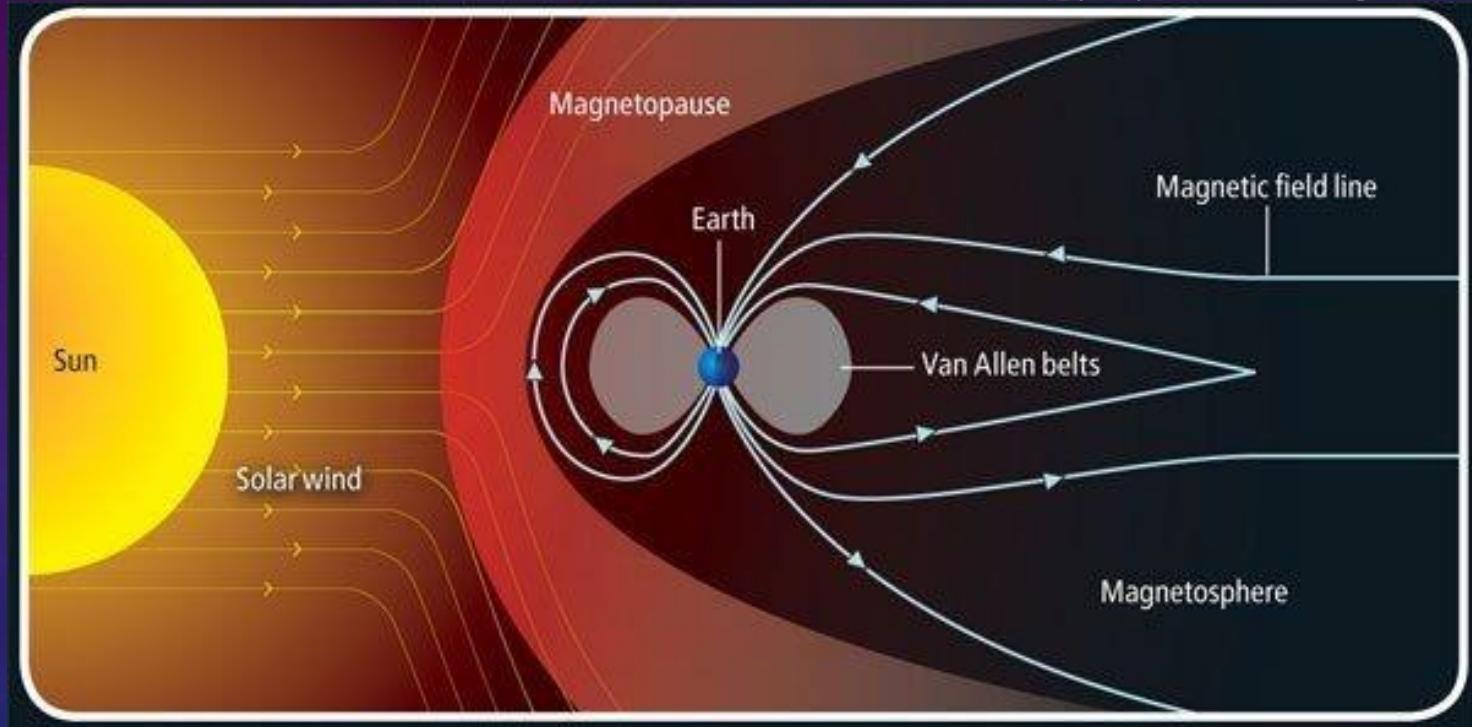
TYPES OF NUCLEAR HAZARDS

MANMADE – Nuclear reactor accidents (Chernobyl 1986, Fukushima 2011),
Nuclear bombs (Hiroshima 1945, Tsar Bomba 1961)
Nuclear waste disposals (Lake Karachay)
Nuclear laboratory accidents (Demon core)

NATURAL - Cosmic ray storms
Natural cosmic ray hazards for astronauts
Uranium mines

NATURAL HAZARDS – COSMIC RAYS

Why does Aurora occur near the poles?



Thanks to the Earth's magnetic field, most cosmic rays are deflected!

SOLAR PARTICLE EVENTS OF 1989, 1859

- Link: [Hu-SPEs.pdf \(nasa.gov\)](#)

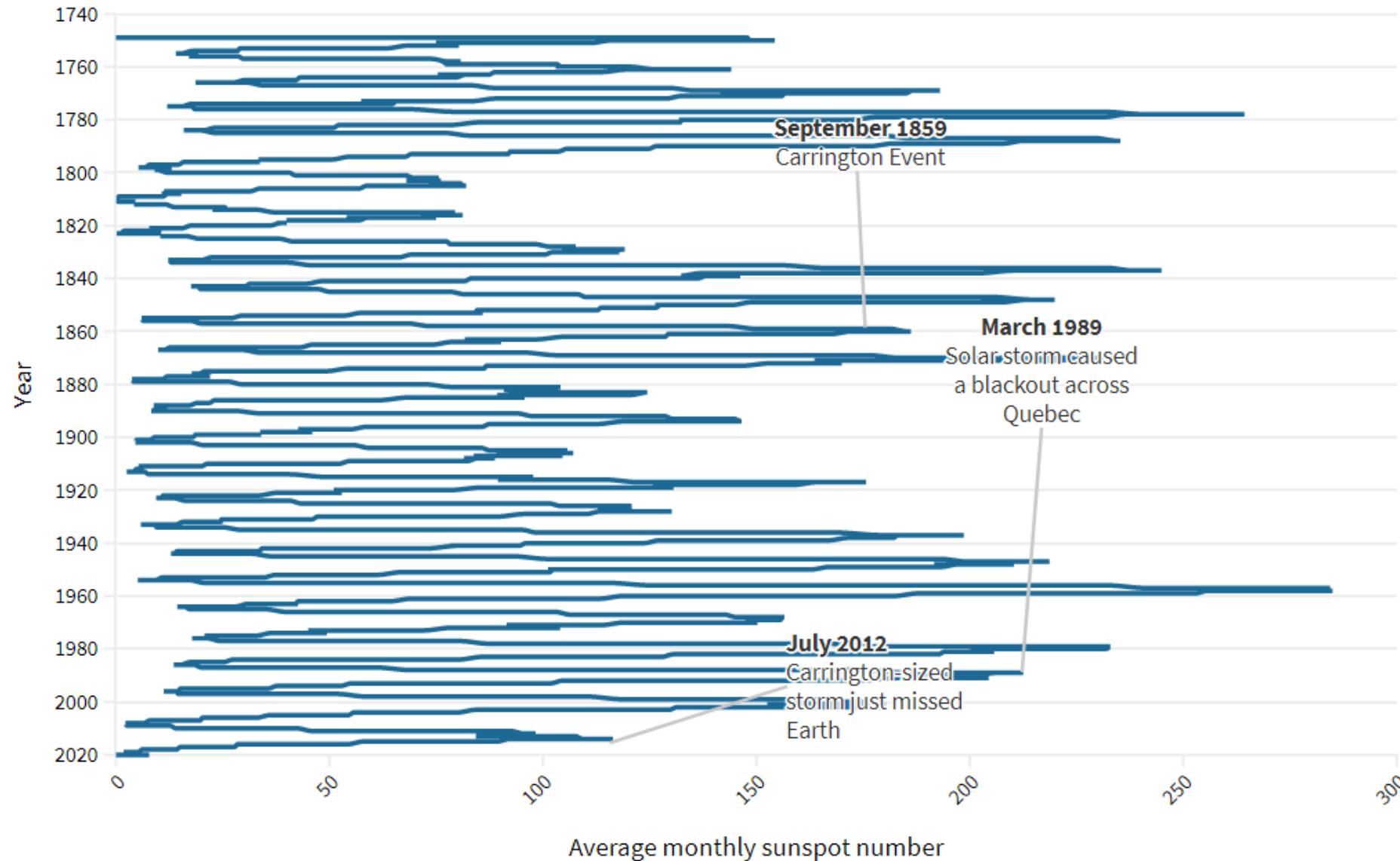


- Coronal Mass Ejections in the sun cause SPEs
- A high energy stream of solar particles (Protons, gamma rays) are ejected towards the earth
- The geomagnetic field can not deflect all the cosmic rays and hence, this can result in potential hazards (electricity lines, communication links, frying of GPS systems, and radiation hazards)

EFFECTS OF SEP 1859 ~CARRINGTON EVENT

- During the Carrington event of 1859, telegraph systems throughout North America and Europe failed
- Many electrified lines shocked and short circuited owing to the intense stream of charged particles
- The effect was more highly pronounced in the **northern hemisphere** because of the then position of the Earth relative to the Sun
- A near Carrington Event occurred in 2012. We use far advanced technology than telegraphs and telephones today and if such an event takes place, the damage to the economy and the health impacts can be catastrophic

Sunspot activity cycles from 1749 to 2020



Source: SILSO data/Royal Observatory of Belgium 2021

HAZARDS, VULNERABILITY AND RISK

HAZARDS

- Magnitude of CME, Duration of CME, Position of the Earth, Strength of Magnetic field

VULNERABILITY

- Population (city/rural), Extend of connectivity by telephone lines, Power grids, Regions of weak magnetic field (more extreme latitudes)

RISK

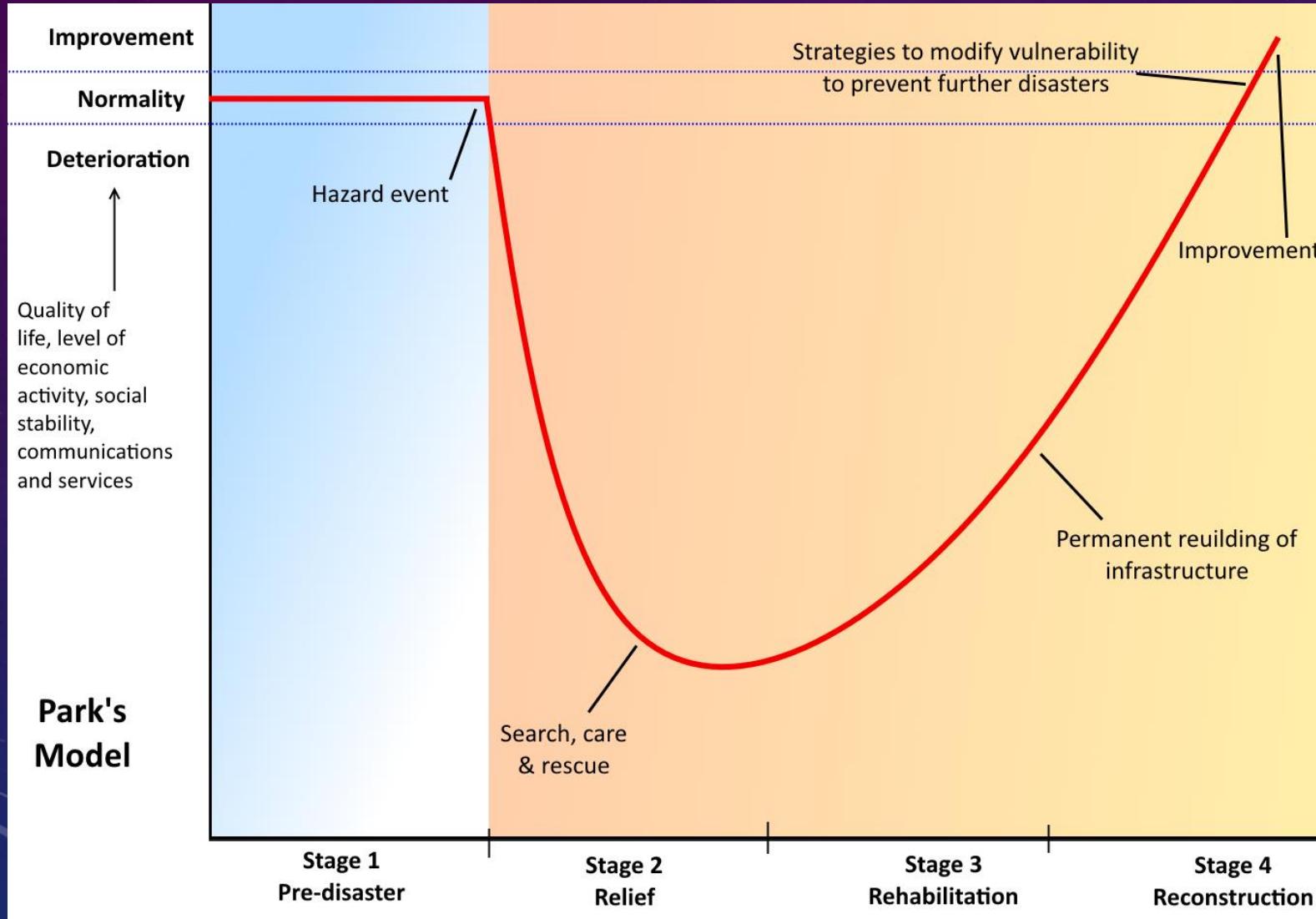
- Electromagnetic instrumentation and radiation hazards; All of this can compound to economic losses

MITIGATION

- 3 P's : Preparation, Prediction and **Prevention**
- **PREPARATION:** Local magnetic fields to deflect particles, Building temporary shelters to protect against possible radiation hazards, Information dissemination to citizens about solar events and their hazards, building a systematic law system for a situation specific to this, equipping satellites with more resistance to radiation
- **PREDICTION:** Better forecasting of CMEs and Solar flares, placing satellites specifically designed for this purpose, documenting and monitoring solar activity
- **PREVENTION:** Can not prevent, but event should be managed effectively

MANAGEMENT

- Short-term, Mid-term and Long-term responses



- **RELIEF:**
to address and Identify all impaired services in a region.
- **REHABILITATION AND RECONSTRUCTION:**
to restore network connectivity, phone lines
- **IMPROVEMENT:**
to build novel equipment that can be employed during a SEP, Improve forecasting abilities, reduce vulnerabilities

GEO MAGNETIC STORMS

- A temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and/or cloud of magnetic field that interacts with the Earth's magnetic field
- Adversely affects technology and human lives
 - Disruption of electrical systems
 - Disruption of communications
 - Damage to navigation systems
 - Satellite hardware damage
 - Radiation hazards to humans (solar protons)

APOCALYPSE

- The movies “**2012**” and “*The Core*” gives us the demonstration of a large scale Geomagnetic storm
- The magnetic field of the Earth is impaired and this causes the solar particles to flow into the atmosphere without being deflected. This magnetic field is thought to exist because of the rotating core of the Earth
- This leads to polarization of air particles almost everywhere, and hence Aurora at almost all latitudes. Further, dangerous UV, X and γ rays enter the atmosphere and can cause skin cancers
- The destruction to human life would be catastrophic, and may mark the end of all civilization on Earth

MANMADE NUCLEAR HAZARD

- Causes the **most destructive** type of disaster
- Can be the result of a natural disaster like Earthquake/Tsunami (Fukushima 2011) or can be due to **human errors** (Chernobyl 1986)
- Can also be the result of deliberate human actions (dumping of nuclear waste in lakes ex: Lake Karachay, setting of nuclear bombs ex: Hiroshima 1945)
- The consequences can be devastating; Causes large scale losses to economies, human lives and steep increase in **birth defects, cancer and mutations**

CHERNOBYL

- On 26th April 1986 , an accident at reactor 4 of Chernobyl Lenin Nuclear Station near Pripyat, Chernobyl exploded and spewed radioactive material in clouds throughout the continent of Europe
- The explosion was a result of a faulty control rod system; Immediately following the explosion, USSR shut off communications from the city of Pripyat in order to maintain secrecy and supremacy but ended up sacrificing a lot of human and animal lives
- The Chernobyl Nuclear disaster is both an example and a non-example of effective disaster management
- I will elaborate on the event and the mitigation steps taken in the following slides

BRIDGE OF DEATH

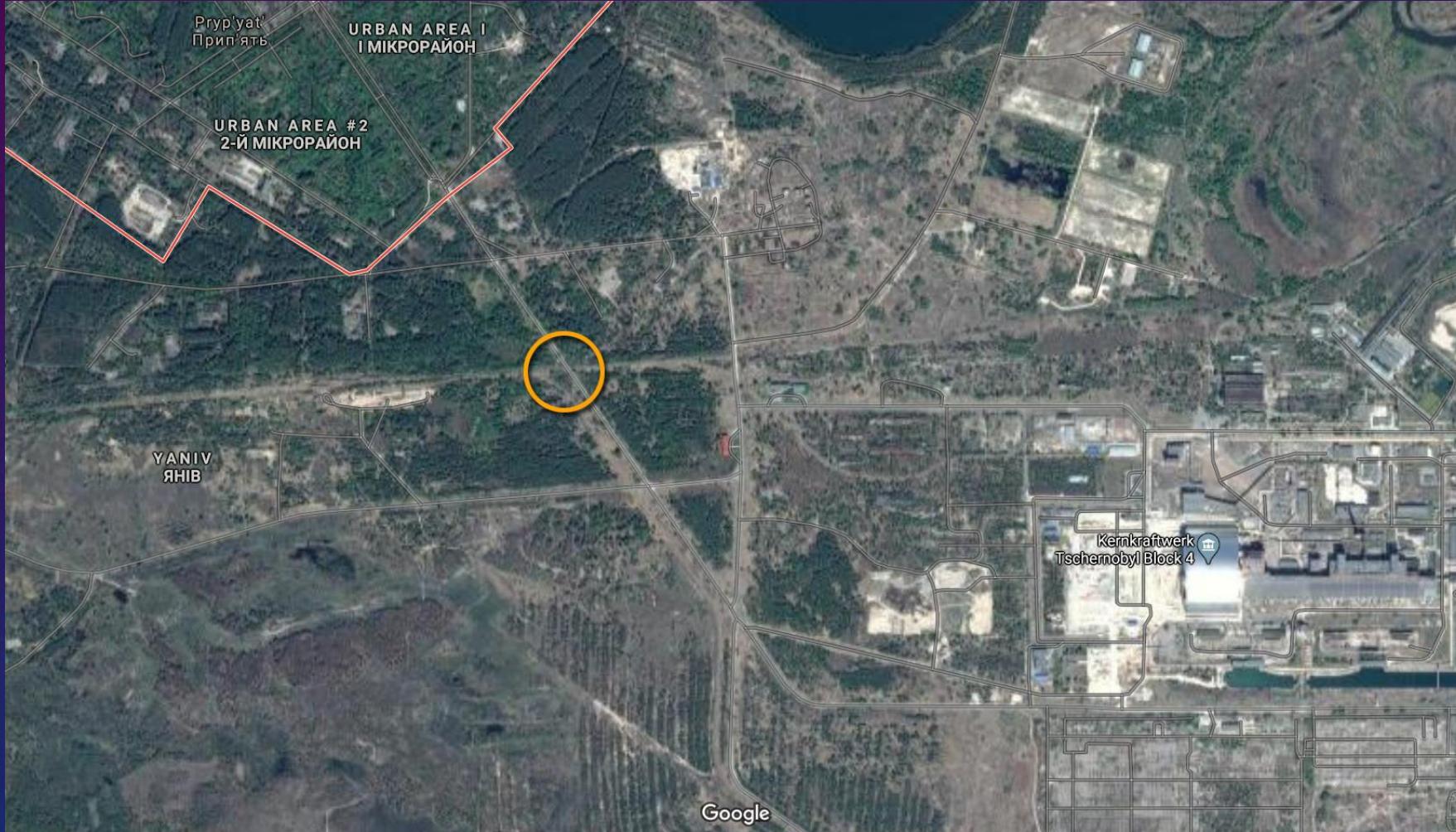


A scene from Chernobyl, HBO dramatization of the event released in 2019



Bridge of Death

BRIDGE OF DEATH







PRIPYAT HOSPITAL



The basement of the Pripyat Hospital, which has clothes and equipment of the firemen. This room remains dangerously radioactive today.

PRIPYAT



The ghost-town of Pripyat



A swimming pool of an abandoned school in Pripyat

LEADING UP TO THE DISASTER

- Incompetent management techniques coupled with rash personal decisions and design flaws in the nuclear core itself caused the core of Reactor 4, Chernobyl Power Plant to explode
- Management downplayed the gravity of the situation and resorted to poor disaster management techniques, like **calling the fire brigade with no equipment to protect from radiation to douse the fire**
- Communication and transportation links were in fact **severed** from Pripyat to the rest of the word when there was need of **immediate evacuation**; It was not until 2 or 3 days that the Soviet government understood that this was a threat to humanity and the Earth as a whole and resorted to better mitigation techniques.

TWO MAIN NUCLEAR HAZARDS

EXPLOSION AND CLOUDS OF RADIOACTIVE DUST

- On explosion, plumes of radioactive dust were dispersed by the winds and spread throughout Europe and Western Russia
- The radioactive Iodine and Caesium present in the dust were very potent and almost always cause cancer in subsequent years

NUCLEAR MELTDOWN

- The radioactive fuel in the reactor core ($U - 235$) melts down into the ground and seeps into groundwater, and into rivers and seas; This was the danger in Fukushima in 2011 but it was well managed
- In Chernobyl, the nuclear fuel has melted down into the basement of the reactor and is known as the “*Elephant’s foot*”

HAZARDS

- There are two types of effects: Deterministic (Immediate) effects and Stochastic effects.

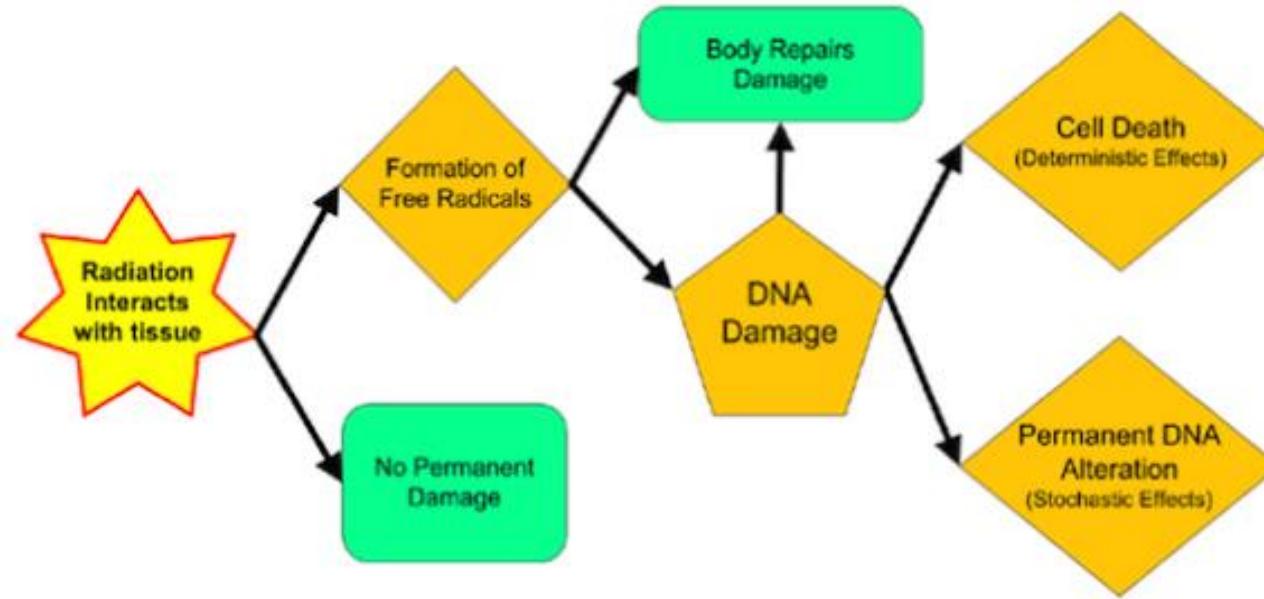
DETERMINISTIC EFFECTS:

- Deaths due to **ARS** (Acute Radiation Syndrome)
- ARS causes large scale cellular death and bone marrow death which results in complete **loss of immunity** and even **decaying away of skin**

STOCHASTIC EFFECTS:

- When the DNA of the cell is damaged, it has internal mechanisms to repair itself. If the damage is too extensive, **cell death** occurs (as in the above case); But if cell death does not occur and the damage to the DNA is not repaired, the resulting DNA is said to be **mutated**. These mutations can manifest in a variety of cancers, autoimmune diseases, aplastic anaemia and bone marrow diseases.

High dose → deterministic effects (acute)
 Lower dose → stochastic effects (delayed)



Effects on Human Body

Classification of Radiation Effects

	Incubation period	e.g.	Mechanism of how radiation effects appear
Categories of effects	Physical effects	Within several weeks = Acute effects (early effects)	Deterministic effects caused by cell deaths or cell degeneration* ²
		After the lapse of several months = Late effects	Abnormal fetal development (malformation)
Hereditary effects		Opacity of the lens	Stochastic effects due to mutation
		Cancer and leukemia	
		Hereditary disorders	

*1: Major symptoms are vomiting within several hours after exposure, diarrhea continuing for several days to several weeks, decrease of the number of blood cells, bleeding, hair loss, transient male sterility, etc.

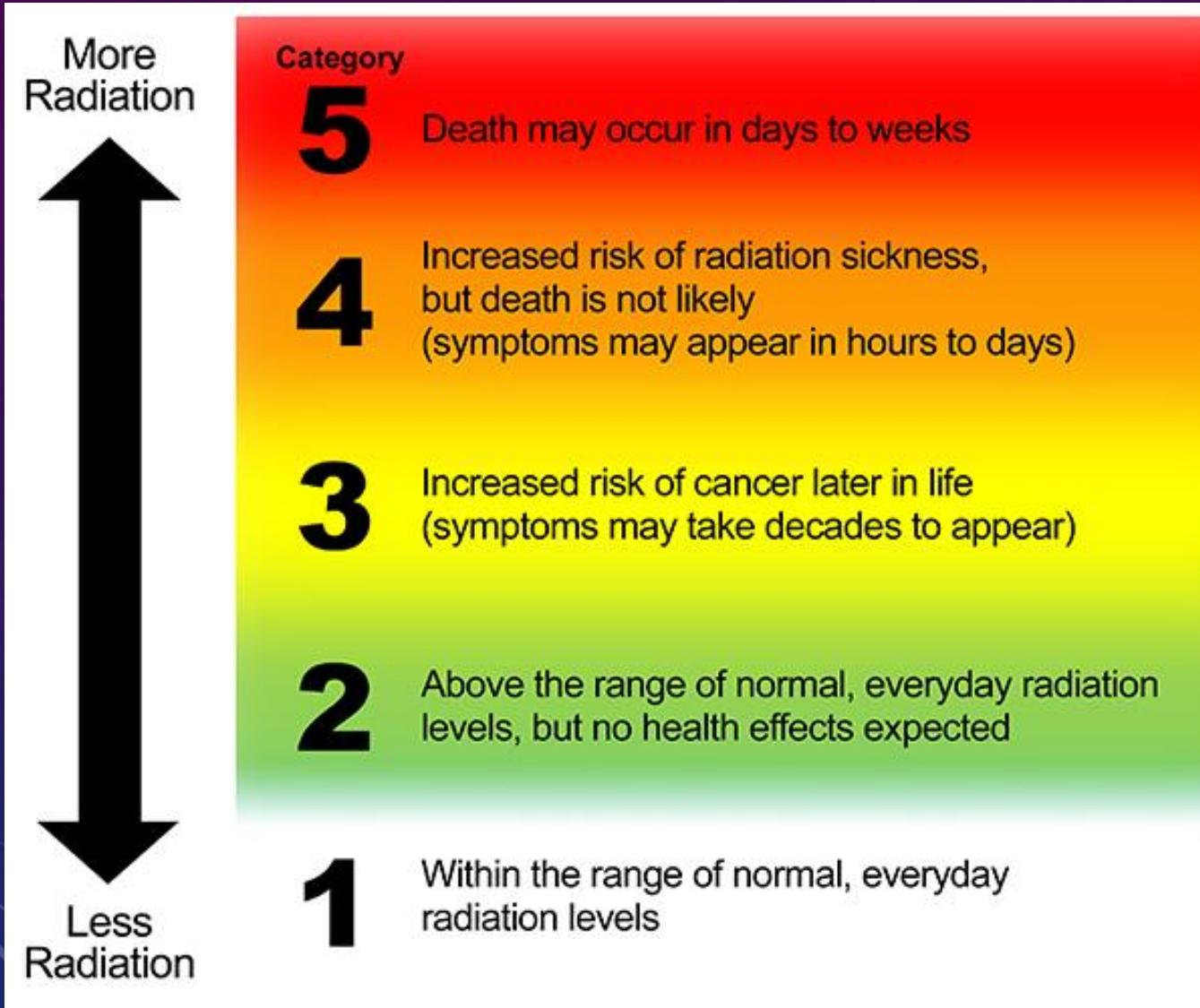
*2: Deterministic effects do not appear unless having been exposed to radiation exceeding a certain dose level.

Deterministic (Immediate) effects vs Stochastic effects

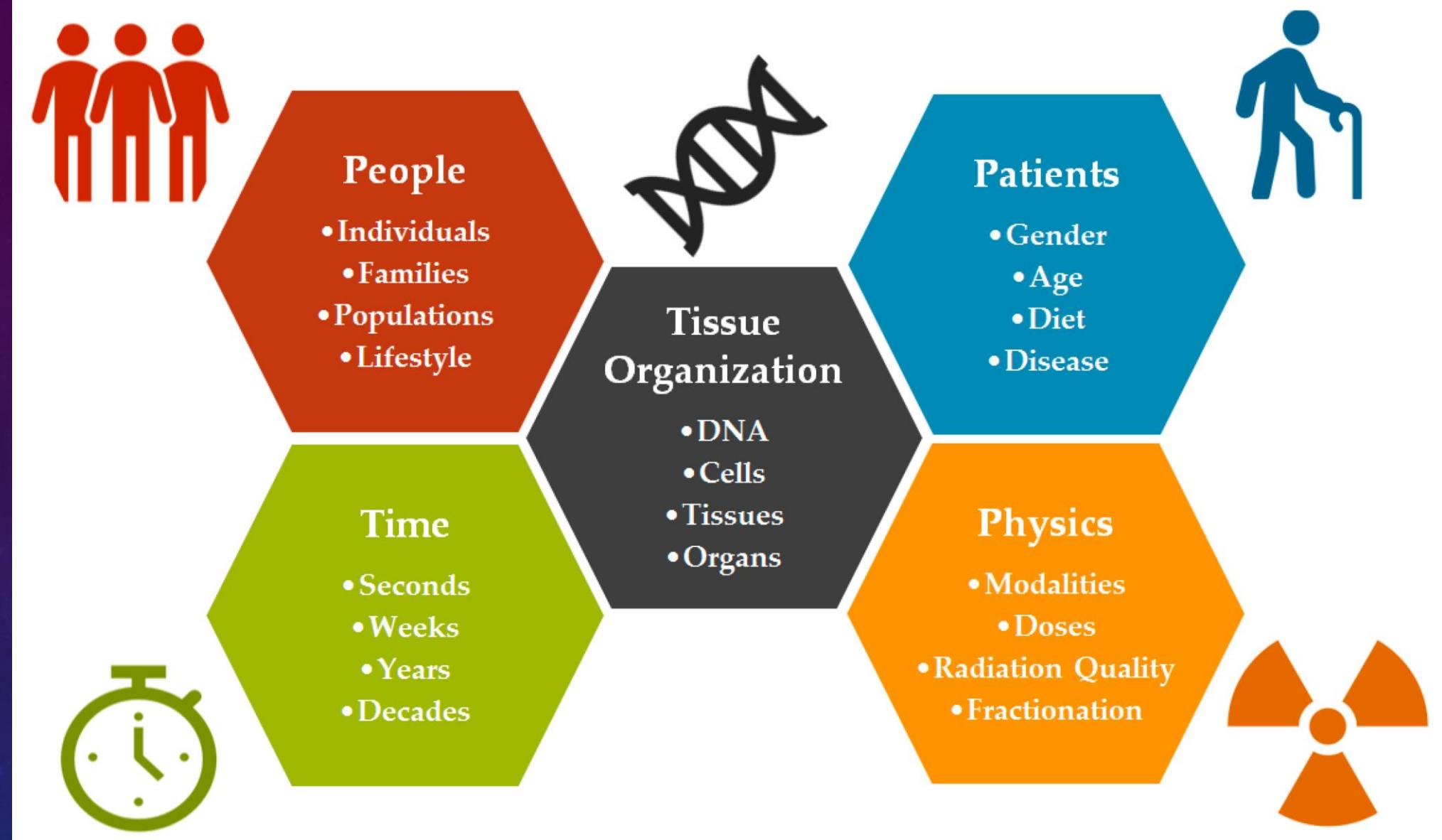
VULNERABILITY TO NUCLEAR DISASTER

- Cities located in and around nuclear power plants
- The working population in the nuclear plant
- The water bodies that inundate regions in and around the nuclear power plants
- The regions depending on this plant for power will be affected adversely
- Individuals who have low immunity

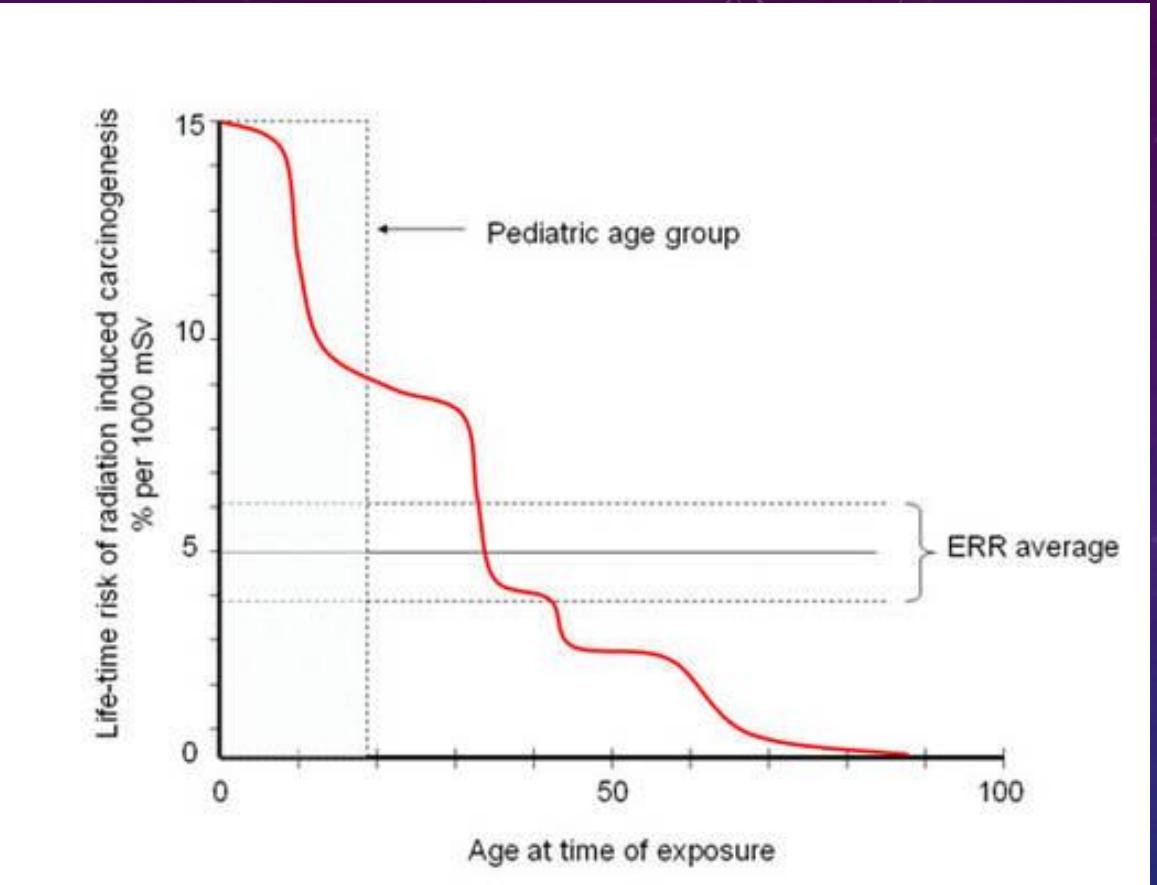
RISKS



5,000 mSv
Half of people exposed to this level in a single dose will die within a month.
1,000 mSv
Causes acute radiation sickness in people exposed to this amount in a single dose.
100 mSv / year
Lowest level that causes a documented increase in cancer risk.
10-15 mSv
CT scan
9 mSv / year
Typical exposure by airline crew flying New York/Tokyo polar route.
2-3 mSv / year
Amount of background radiation people are generally exposed to each year.
.2 mSv
Chest x-ray
.01 mSv
Dental x-ray

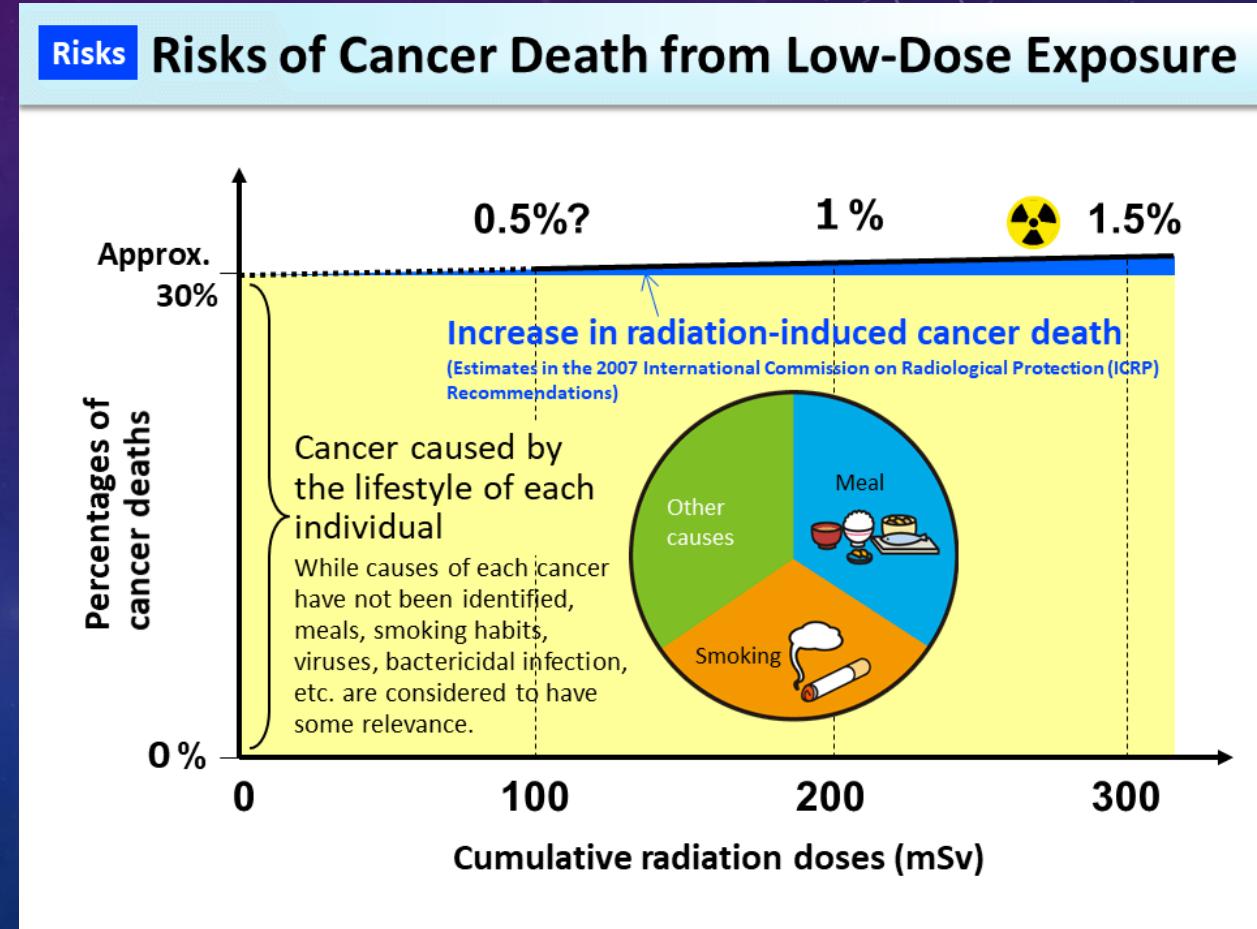


Demographic transition and factors associated with remaining in place after the 2011 Fukushima nuclear disaster and related evacuation orders (plos.org)



Risk of carcinogenesis decreases with increase in age

Other factors which influence radiation doses- induced carcinogenesis



MITIGATION – RADIATION PLUMES

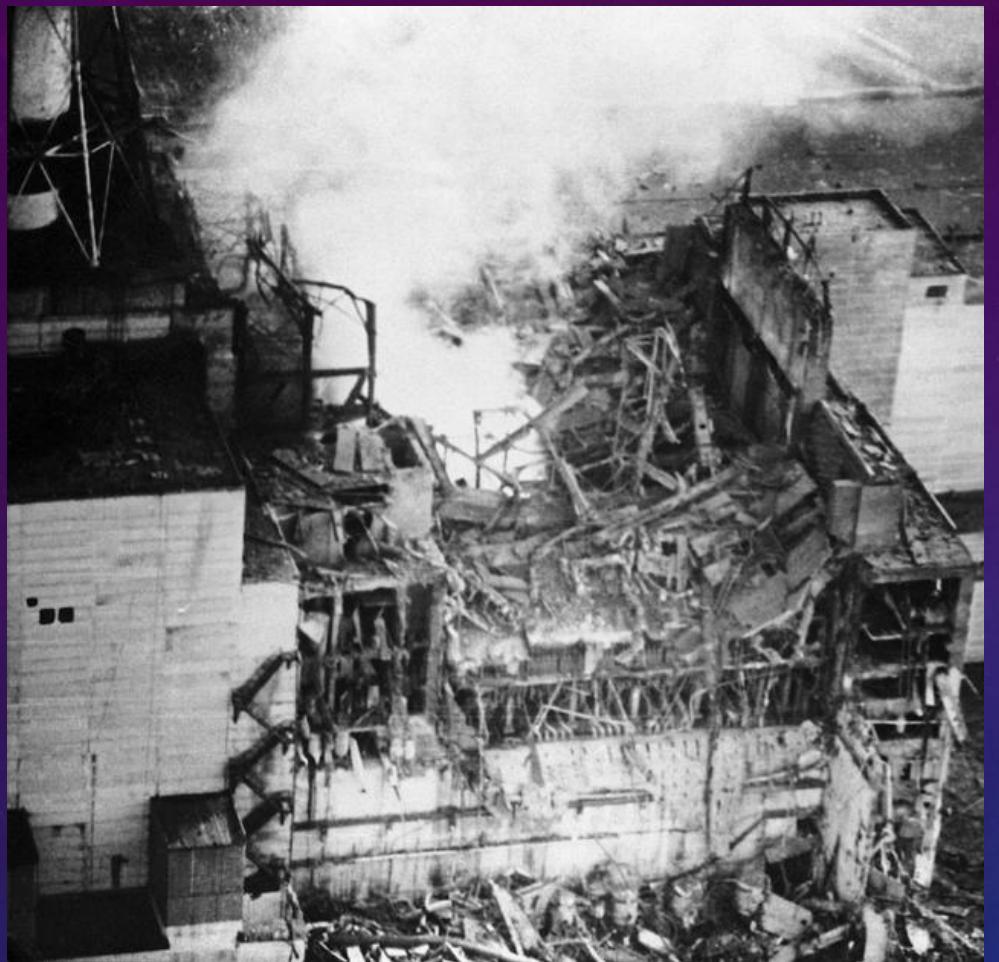
- **PREVENTION:** The safest method! If any anomaly occurs in a nuclear setting, it is the safest and option to turn off all nuclear activity (through control rods or appropriate environment in a laboratory)
- **PREDICTION:** Whenever a large scale nuclear disaster is imminent, immediate warnings should be issued throughout the state/nation; Predictions should take into account the worst possible scenario
- Predictions of wind profiles must be issued
- **PREPARATION:** The governments must prepare for large-scale evacuations and setting up an **Exclusion zone** around the region of explosion. They should also issue guidance to citizens about how to protect themselves from radiation clouds and to stay inside. **Ground shelters** must be incorporated from existing underground reserves

SHORT TERM RESPONSE

- Immediate evacuation of the surroundings depending upon the intensity of explosion (Chernobyl ~ 30 km radius, Fukushima ~ 10 km radius)
- Providing immediate health care to those who have received moderate-high radiation doses and gauging their situation; this includes **risk assessment** and calculating their probable received dose
- **Radiation fires** must be kept in check by dumping sand (and possibly neutron absorbers like Boron to control rate of nuclear reaction)
- Equipping hospitals with radiation protection equipment and palliative care (morphine drips)

MEDIUM TERM RESPONSE

- Evacuation of the exclusion zone and cleansing; this includes all animals that live in the exclusion zone (if they are allowed to live, they spread radioactive contamination)
- Providing a detailed count of ARS-related deaths from the nuclear explosion and estimate mutations in the near future
- Cleaning of the explosion site of radioactive material ([Chernobyl 3828 - YouTube](#))
- Building a **temporary containment** to stop the spread of radioactive plumes and smoke

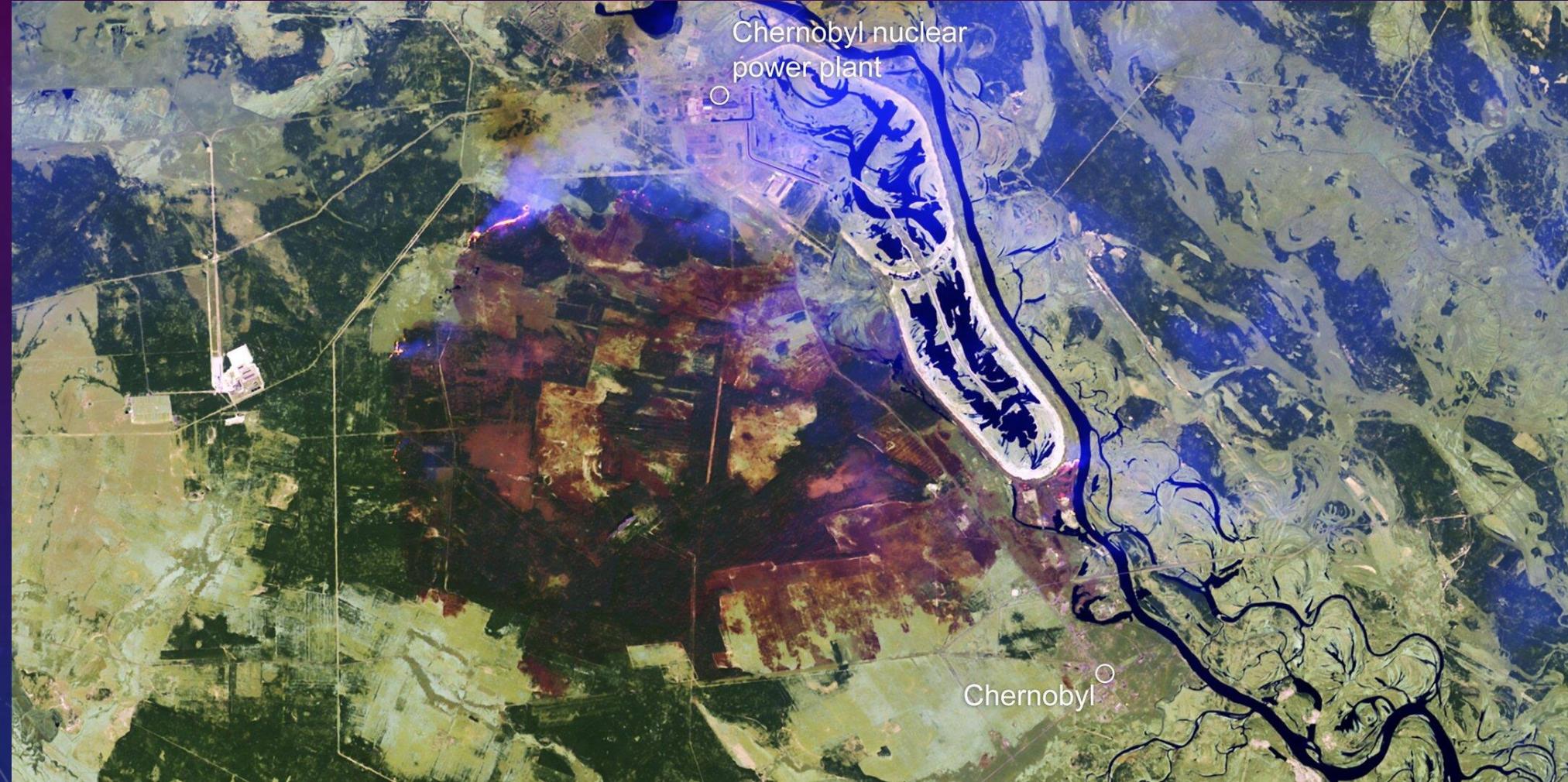


Real image of the exposed core of Reactor 4



Computer generated colour-modified image of the exposed core of Reactor 4

SATELLITE MAPPING OF RADIOACTIVE SMOKE



LIQUIDATORS

- The **Chernobyl liquidators** were the civil and military personnel who were called upon to deal with consequences of the 1986 Chernobyl Nuclear disaster in the USSR on the site of the event. The liquidators are widely credited with limiting both the immediate and long-term damage from the disaster
- Three liquidators went underneath the reactor and prevented a steam explosion that could have blown the rest of the reactors and rendered Europe inhabitable. Two of them are still alive to this day, despite the radiation exposure and none of them died due to immediate causes!
- **Fukushima –50** was a similar group of 50 employees who were appointed in the 2011 Fukushima Nuclear disaster
- Many of these liquidators are alive today and are granted veteran status and high respect in the world

CLEANING OF THE REACTOR ROOF



*Liquidators cleaning
the roof of reactor 4
of Chernobyl
Nuclear power plant*

PRIMARY CONTAINMENT



LONG TERM RESPONSE - EXPLOSION

- Following up on the numbers of ARS related deaths, and mapping the cases of cancer and birth defects to the radiation exposure
- Gradual occupation of the exclusion zone and reconstruction of industries and service sectors in less affected areas; However this depends on the extent of radiation that is still present; Chernobyl still has a strict *30 km* exclusion zone and will be uninhabitable by Humans for at least **1000 years** whereas Fukushima's exclusion zone has been reduced in area; However, the epicentre will still be dangerously radioactive
- Following up on the **biodiversity levels** in the exclusion zone and study the effects of radiation on flora and fauna
- Setting up radiation measurement devices throughout the exclusion zone
- Creating a **better containment** around the explosion area

NEW SAFE CONTAINMENT

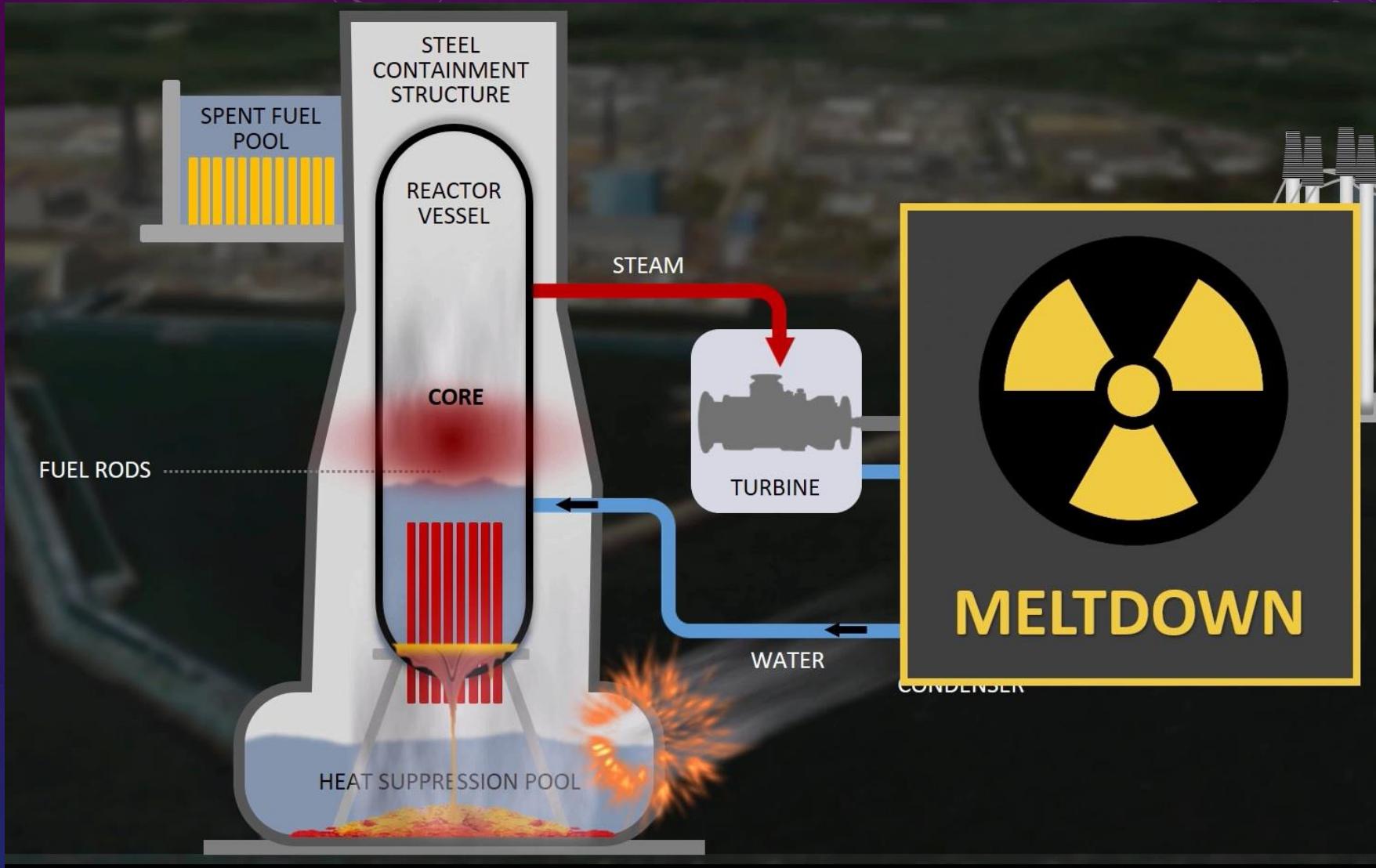


- Joint venture by the European Union and the Ukrainian government
- Started construction in September 2010, completed in July 2019
- Cost **2.1 Billion Euros**

RED FOREST



The 10 km radius area surrounding the site of explosion is permanently closed; the trees have changed colour due to radioactivity and have become red; This forest is contaminated to this day



Meltdowns are very serious disasters and require long term management techniques

MEDIUM-LONG TERM RESPONSE - MELTDOWN

- Meltdown is another serious consequence of a nuclear disaster where the hot fuel melts down into the ground and gets into the groundwater
- To prevent a meltdown, a heat exchanger must be set up between the ground and the nuclear reactor, with contents like Liquid Nitrogen which absorbs a lot of heat
- More foundations of concrete must be constructed below the basement of the reactor to prevent the fuel from melting into the groundwater
- In Chernobyl and Fukushima, the meltdown was managed well and in Chernobyl, 400 Coal miners were called to build a tunnel below the reactor to set up a Liquid nitrogen heat exchange. They too were awarded liquidator status. 1 in 4 of them perished due to cancer or radiation related illnesses.

THE ELEPHANT'S FOOT - MELTDOWN



The *Elephant's foot* as of December 1986 consisted of a mix of various materials; nuclear fuel, melted concrete, core shielding, and sand, all mixed together. This substance was then named 'Corium' or Lava. This still exists underneath the reactor and is extremely radioactive

IMPROVEMENT

- Following the incident of Chernobyl, the faulty reactors in the Soviet Union were repaired by replacing the control rods
- We now have studied the effects of radiation on a variety of flora and fauna
- We were able to handle the Fukushima disaster in 2011 very well after the Chernobyl disaster in 1986
- The area around Chernobyl (even reactor 4 itself) is now a tourist attraction and generates revenue for the Ukrainian government; 26th April 2036 will be the **50'th anniversary** of the accident and it is my dream to visit it on that day!