Radiation from food is high in Japan because of high polonium intake from seafood.
Inhalation of radon is low in Japan because of natural ventilation of housing.

Possible additional dose living in 0.15μSv/h and having 20Bq of Cs137 365 days.
Terrestrial 0.6 + Food 0.1 = 0.7
Radiation around the world (μSv/h)

Composed by Tohoku University. Radiation level varies from place to place. In Hong Kong it ranges from 0.05 to 0.25 μSv/h. In New York it ranges from 0.01 to 0.25, mostly 0.1 μSv/h.
Researchers say if you receive 100 millisieverts your cancer death risk would rise 0.5% in your lifetime.
The radioactive emission on March 12th caused contamination of body surface to more than 100 people.
Transition of air dose rate

After 7 months
(2011.11.05)

4th Monitoring

After 11 months*
(2011.02.10)

4.5th Monitoring

After 15 months
(2012.06.28)

5th Monitoring

After 20 months
(2012.11.16)

6th Monitoring

After 24 months*
(2013.03.11)

6.5th Monitoring

After 30 months
(2013.09.28)

7th Monitoring

*White parts surrounded by solid line are snow covered zones
The evacuation order was expanded from a 3 km radius on March 11th to 20 km next day. The 30 km radius was designated as ready-to-evacuate area. The 20 km radius was restricted to enter by gates on April 22nd.
Transition of evacuees

[unit: person]

Evacuees outside the prefecture
Evacuees inside the prefecture
Missing

Registry of evacuee children under the age of 18
(divided by the destinations of evacuation)

[unit: person]
Minamisoma City divided into four by compensation

Difference of compensation have made division among Fukushima residents. Minamisoma City was divided into four area, which made political turbulence and division in community. The then mayor Katsunobu Sakurai, who was selected as one of Time magazine's 100 most influential people in the world in 2011, lost the election in 2018.

<table>
<thead>
<tr>
<th>Compensation of mental damages</th>
<th>Compensation of property</th>
<th>Medical care</th>
<th>Highway toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] 80,000 JPY</td>
<td>0%</td>
<td>70% paid by insurance</td>
<td></td>
</tr>
<tr>
<td>[ ] 2 million JPY</td>
<td>0%</td>
<td>Free</td>
<td>Free</td>
</tr>
<tr>
<td>[ ] 8.5 million JPY</td>
<td>90%</td>
<td>Free</td>
<td>Free</td>
</tr>
<tr>
<td>[ ] 14.5 million JPY</td>
<td>100%</td>
<td>Free</td>
<td>Free</td>
</tr>
</tbody>
</table>

City government paid 400,000 JPY to the residents of the white area to alleviate the gap and covers high way toll of them.

Odaka locates within 20 km radius of Daiichi NPP. If you have a very old 200 m² house in Odaka and build a new house under 200 m² out of 20 km radius, TEPCO pays the whole cost of the new house as a compensation. National government pays for demolishing cost of the old house. It urged Odaka residents to move out of Odaka.
Population of evacuation zone

88,000 before the accident

11,000 at December 2018

Most already settled their life out of this area, where is more convenient, better for education, lower radiation.
Damage of the triple disaster

The earthquake occurred 14:46 March 11, 2011. Tsunami hit the coast of Tohoku 50 minutes after the quake. Number of missing and dead in Japan reached 18,500
In Fukushima prefecture
- Number of missing and dead 1,831
- Disaster related death 2,000
- Number of evacuees 160,000 in May 2012
- Number of evacuees 46,000 in May 2018
- Number of contaminated soil bags 16 million
- Population of former evacuation zone 88,000 → 10,000
Radioactivity air dose rate at eight points

- Radioactive plume passed over Minamisoma and Iwaki several times. Maybe main content was gas like radioactive Xenon and Iodine131.
- Plume got down to the ground in Fukushima City and Iitate. It contained Iodine131 and Cesium137/134.

---

R1 exploded 3/12/15 15:36
R3 exploded 3/14/11:01
R4 exploded 3/15/06:14

R1 vented 3/12 14:30
R2 leakage made major contamination

12th 8PM Fukushima
15th 6PM Minamisoma
15th 4AM Iwaki

Iitate
SPEEDI was designed to predict contamination with ERSS data, meteorology data and geographic data and proposes area of evacuation. But SPEEDI didn’t work when needed.

ERSS obtains data such as temperature, pressure, radioactivity of stacks and forecasts the leak of radioactive materials.
SPEEDI, a computer simulation system developed to predict dispersions of radioactive substances, couldn’t predict anything but the wind direction because radiation sensors at chimneys of Daiichi lost electricity. No one could predict when and where radiation leaks would occur. The below were simulation if Daiichi was to leak 1Bq every hour. Radioactive plume didn’t come when we were ready for it at 9AM, 2PM and 3PM. It actually came when we were not anticipating it at 5PM and 8PM.

9AM vent of reactor#1 was ordered

2:30PM R#1 Vented

3:36PM R#1 exploded

5PM 900μSv/h detected at Futaba Town

8PM 17.08μSv/h detected at Minamisoma
Behavior of Cesium

Cesium137 stays in surface of the ground.

- Soluble Cesium
- Cesium trapped by organic substance
- Cesium trapped clay mineral

Weathered Clay Minerals

- Too wide
- Suitable

Cs sorption is energetically stable

Clay minerals adsorb Cs
Water contain few Cesium

Stream water in the forest, where air radiation rate is 60μSv/h, contains only 1 Bq of Cesium per litter.
Timeline: Fukushima Daiichi(No.1) Accident

March 11 14:46 A 9.1 magnitude earthquake strikes off the coast of Fukushima
15:46 A 14-metre (46 ft) tsunami strikes the plant disabling the backup
diesel generators

March 12 14:30 Reactor 1 vents successfully
15:36 Reactor 1 building explodes

March 14 11:01 The unit 3 reactor building explodes
20:00 Core damage starts occurring in reactor 2.

March 15 06:10 Reactor 4 building explodes
06:20 Pressure of Reactor 2 decreases with a sound of explosion
09:00 Radiation monitor at Daiichi main gate detects 12mSv/h
15:00 Radiation rate starts increasing at Fukushima City to 24μSv/h

Unit #1,2 and 3 got meltdown.
Hydrogen explosion occurred at unit #1,3,4.
Daini has 4 reactors with 1.1GW turbine unit each. Tsunami flooded them and cooling systems got down. Evacuation was ordered to 10km radius. Luckily 1 of 4 power lines survived. TEPCO renewed flooded motors of cooling systems and connect them with the survived power line setting 9 km of cables by 200 workers. It was three hours before the planned vent when the cooling system resumed. TEPCO succeeded to cool down the four reactors on March 15th. This is called Daini’s miracle. It saved east Japan.

Tsunami ran up a road and flooded all four reactor units. Two hundreds of TEPCO workers carried and set 9 km of cable. They renewed cooling system motors.
Fukushima Daiichi (No. 1) Nuclear Power Station

Reactor #6 & #5

Unit #1 & #2 → #3 → #4

Unit #1 - meltdown & exploded
Unit #2 - meltdown
Unit #3 - meltdown & exploded
Unit #4 - exploded

Fuel removal completed 1535/1535 Dec 22, 2014

Cooling water injection

* Comenced on removing rubbles from Unit 1 operation floor on 22nd Jan. 2018
(2) Sea Area Monitoring Status

The radioactive material concentration in the sea area by one–1,000,000th after the accident
Radioactivity in the ocean

Human and natural sources of radioactivity in the ocean

Global nuclear weapons testing, 1950s-'60s

- 400 peta-Bequerels (PBq)

Chernobyl

- 85 PBq

Three Mile Island

- 0.00004 PBq

Fukushima

- Atmospheric
  - 10-30 PBq
- Direct
  - 3-30 PBq

Fukushima released 3 to 30 peta-Bequerels of radioactive cesium-137 directly into the sea and 10 to 30 PBq into the atmosphere, of which about 50% eventually ended up in the ocean.

Three Mile Island released 0.00004 PBq entirely into the air.

Chernobyl released 85 PBq, mostly into the air.

Nuclear weapons tests released 400 PBq over several years. The majority has eventually landed in the sea.

Potassium-40

- 15,000,000 PBq

Though serious, these totals pale compared to the abundance of radioactive substances naturally present in seawater such as uranium-238 and potassium-40.

NOTE: colored ovals not drawn to scale.
Tritium water tanks occupy the Daiichi site

There are 860 tanks, which contain 1 million tons of Tritium water, 1 Mega Bq tritium per litter. Tritium amounts 1 Peta Bq. Government and TEPCO want to release it to the ocean with the limit of 60000 Bq/L but fisher men and many people are against the plan.

[What is Tritium]

- H3 – one proton with two neutrons
- Exists as HTO or TTO(normal water is HHO)
- Physical half life time - 12 years
- Effective half life time – 12 days
- Emits β particle with 0.0186 MeV
- Sea water contains 0.1Bq/L
- Rain water contains 0.3Bq/L
- Daiichi released 2 Trillion Bq of tritium to the ocean in a year before the accident.
- Nuclear fuel reprocessing facility in UK or France releases 1-10 Peta Bq in a year
- Biological effect of swallowing Tritium is 1/344 of Potassium 40.
Workers at F1NPP

◆ About 4000 people are working in the F1NPP site.
◆ Most of them work from 4 AM to 1 PM in summer to avoid hot or windy daytime.
◆ On March 11th two workers were drowned by tsunami.
◆ Six workers have been paid as compensation of cancer or leukemia by Industrial Accident Compensation Insurance. A worker who died of lung cancer had 100 mSv after the nuclear accident. He had another 100 mSv before the accident at F1NPP. Another worker in his 50s received 100 mSv right after the accident and got thyroid cancer.
Nuclear Reactors in Japan as of February 2019

- 4 reactors – Meltdown or exploded
- 17 reactors – Decided to be decommissioned after Fukushima accident
- 3 reactors – Already decided to be decommissioned before Fukushima accident
- 9 reactors – Resumed under new regulation
- 3 reactors – Under new construction
- 24 reactors - Suspended
Thirty year soil storage area
Thirty year soil storage area - Process

Separation facility

Soil storage

Soil bags to be carried in 30 yr soil storage area

- 2019 – 4 million m³
- 2018 – 1.8 million m³
- 2017 - 0.5 million m³

Non burnable

Burnable

Incinerator with Cesium filter

Ashes

16 million m³ in total
Dificulties of elderly home patients
1. Shortage of vehicles
2. Long distance evacuation
3. Lack of caretakers
4. Hard situation of evacuee camp
5. Hard to find their new home

One hundred of patients at Sunlight Okuma safely evacuated by bus with caretakers in the morning of March 12th 2011.
Futaba Hospital

Forty six patients at Futaba Hospital died during evacuation. Four patients were found dead in Futaba Hospital one month after the accident.

There were 338 patients and 149 staff members in the hospital when the earthquake occurred. More than 200 could walk by themselves and evacuated by bus.

All staff evacuated by 8 PM March 14th and 90 patients were left since the reactor #2 were thought to be serious condition.

SDF took them out of town by 0:30 March 16th
Measurements to the nuclear accident

Headquarter building for nuclear disaster measurement were located 5km west of Daiichi. It was too close. It lost telecommunication. Radiation level outside of the building reached 1800μSv/h. Members evacuated on March 15th.

Municipal governments had iodine pills but most didn’t distribute them to their citizens.
Futaba Medical Center opened 23rd April 2018

- Number of Ambulant Patients in FY 2018
  - January: 351
  - March: 265
  - August: 308
  - Other months vary from 156 to 262

- Ambulant patients in FY2018: 2,752 = 8/day

- Inpatients in FY2018
  - Number: 3.9/day (Max 11/day)
  - Average age: 72 years old
  - Average stay: 8 days

Main patients: Heatstroke in summer, flu in winter.
Number of patients in FY 2018: 2,752 = 8/day
Ukedo district in the town of Namie

Before

After

Evacuation
Fish nursery
Kumamachi Elementary School
Thyroid cancer and suspected cases - 190

Increased Cancer Risk by Age at Exposure to 100 mSv Radiation

Age distribution of thyroid cancer, Japan 1975 - 2007
Mutation caused by the nuclear accident?

Deletions of leader shoots of fir trees

Fukushima flower

Unbalanced swallow tail

the pale grass blue butterfly
## Total cost

<table>
<thead>
<tr>
<th>Who pay?</th>
<th>Decommission</th>
<th>Compensation</th>
<th>Decontamination</th>
<th>Soil storage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEPCO</td>
<td>¥8 ($75)</td>
<td>¥3.9 ($37)</td>
<td>¥4 ($38)</td>
<td></td>
<td>¥15.6 ($147)</td>
</tr>
<tr>
<td>Major electric companies</td>
<td></td>
<td>¥3.7 ($34)</td>
<td></td>
<td></td>
<td>¥3.7 ($34)</td>
</tr>
<tr>
<td>New electric companies</td>
<td></td>
<td>¥0.24 ($2)</td>
<td></td>
<td></td>
<td>¥0.24 ($2)</td>
</tr>
<tr>
<td>Government</td>
<td></td>
<td></td>
<td>¥1.6 ($15)</td>
<td>¥1.6 ($15)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>¥8 ($75)</td>
<td>¥7.9 ($73)</td>
<td>¥4 ($38)</td>
<td>¥1.6 ($15)</td>
<td>¥21.5 ($202)</td>
</tr>
</tbody>
</table>

GDP of Japan is 5 trillion USD (2016)
Serious damage caused by the accident

Anti-nuke people
Anti-government people
Radiophobia
The media

- exaggerate the damage of radiation
- distort the facts
- cause the health concern of local people

• Different perceptions of radiation caused division among family members and community
• Conflicts on the damage of radiation causes a big stress
• Elder generations returned home but not younger generations
• Shortage of caretakers, workers, students, consumers

Namie Elementary and Junior High School has 9 students in 9 grades.
Difficulties of severe nuclear accident

1. <No drill> Drilling for severe nuclear accident is impossible. You must cope with unexpected multiple crisis at a time.

2. <No prediction> Radiation leaks can’t be foreseen. Hydrogen explosion nor “vent” didn’t cause a major contamination. Major leaks came in silence.

3. <No local government> Municipal governments don’t work. They have to evacuate too.

4. <No helper> No rescue, no bus, no gas, no food in 30 km radius. Most drivers rejected to get into 30 km radius.

5. <Not acceptable> Evacuees can’t be accepted without checking body surface contamination. We didn’t have checker devices. Major cities declined accepting evacuees.

6. <Can’t save> Doctors and nurses can’t save their patients’ life. Engineers at nuclear power plant can’t save their plant. They also have families they have to save.
Developing renewable energy

- Black line is TEPCO grid. Blue and purple lines are owned by Tohoku Electric Power Co. Green line connects the both. Tohoku declines to accept renewable energy because of less capacity.

- Fukushima Daiichi(1F) and Daini(2F) don’t generate but consume electricity. Fukushima government proposed TEPCO to lower the voltage from 275 kV to 66 kV and open it for renewable energy. TEPCO did it for free.

- Fukushima Prefectural Government put wind energy zone and did environmental assessment.

- Fukushima government is putting underground cable connecting TEPCO grid for wind farms and solar parks.

- The renewables will be 500 MW in total.

- One million JPY per 1 MW will be donated for rebuilding communities every year.

- Fukushima Prefectural Government declared renewable energy 100% March 2012. It means that Fukushima produces renewable energy more than the whole amount of energy Fukushima consumes in its area.
By unanimous decision, this tour is over.

Dark Tourist
Episode 2
Filming locations
Penetrating power of radiation

Alpha particles are the heaviest and most highly charged of the nuclear radiations. Alpha particles cannot travel more than four to seven inches (10 to 18 cm) in air and are completely stopped by an ordinary sheet of paper.

Beta particles are smaller and travel much faster than alpha particles. They are physically similar to the electrons, but they are not in orbit around an atom. They penetrate further into any material or tissue.

Gamma rays are the most hazardous type of radiation from sources outside the body because they can travel much greater distances through air and all types of material.

You should be careful about inhalation of Radon(α), ingestion of Cesium(β) and Polonium(α), external doce of Cesium(γ) and medical x-ray to live in current Fukushima, which can be reduced. Cosmic ray and Potassium40 are inevitable.
Radiation follows an inverse square law

Intensity of radiation is inversely proportional to the square of distance from the source.

\[
\frac{S}{4\pi r^2} = I
\]

The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.

It’s all about Distance Inverse-Square Law
Radiation Units

Radioactivity 放射能
- 1 decay/sec = 1 Bq (Becquerel)
  1Bq of Cs 137 contains 1.3 billion Cs atom.
- 37 billion Bq = 1 curie

Absorbed Dose 吸収線量
- The amount of energy deposited by radiation.
- 1 joule/kg = 1 Gy (Gray) 1 Gy = 100 rad

Equivalent Dose 等価線量
- Equivalent dose is calculated for individual organs.
- It considers the danger of different radiations. 1 Gy of alpha is 20 times more dangerous than 1 Gy of gamma/beta/x-ray.

Effective Dose / Whole Body Dose 実効線量
- Calculated to assess the potential effects to your whole body.
- Effective dose = sum for all organs of equivalent dose times the appropriate tissue weighting factor (sensitivities of the body parts).
- The unit is Sv(sievert). 1 Sv = 100 rem
- As for gamma and beta, 1 Gy = 1Sv
Does eating a banana increase your radiation dose?

A 60 kg of human body contains
Potassium 40 (K-40)  4000 Bq
Carbon 14           2500 Bq
Rubidium 87         500 Bq
Lead210/Polonium210 20 Bq

The average banana contains 15 becquerels of potassium 40. Nevertheless, eating that banana does not add to the annual radiation dose of the human being who eats it.

Human body keeps a certain amount of potassium. 0.012% of potassium is radioactive K-40. Any new potassium ingested is balanced by eliminating a comparable amount of potassium to maintain the homeostasis of the body.
Effective dose coefficients for ingestion (μSv/Bq)

<table>
<thead>
<tr>
<th></th>
<th>Iodine 131</th>
<th>Cesium 134</th>
<th>Cesium 137</th>
<th>Potassium 40</th>
<th>Strontium 90</th>
<th>Tritium</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 months old</td>
<td>0.48</td>
<td>0.026</td>
<td>0.011</td>
<td>0.052</td>
<td>0.13</td>
<td>0.000064</td>
</tr>
<tr>
<td>1 year old</td>
<td>0.18</td>
<td>0.016</td>
<td>0.012</td>
<td>0.042</td>
<td>0.073</td>
<td>0.000048</td>
</tr>
<tr>
<td>5 years old</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0096</td>
<td>0.021</td>
<td>0.047</td>
<td>0.000031</td>
</tr>
<tr>
<td>10 years old</td>
<td>0.052</td>
<td>0.014</td>
<td>0.01</td>
<td>0.013</td>
<td>0.06</td>
<td>0.000023</td>
</tr>
<tr>
<td>15 years old</td>
<td>0.034</td>
<td>0.019</td>
<td>0.013</td>
<td>0.0076</td>
<td>0.08</td>
<td>0.000018</td>
</tr>
<tr>
<td>Adult</td>
<td>0.022</td>
<td>0.019</td>
<td>0.013</td>
<td>0.0062</td>
<td>0.028</td>
<td>0.000018</td>
</tr>
</tbody>
</table>

- If you eat 30g of mushrooms that contain 1000 Bq/kg of Cs 137, your effective dose is: $0.03 \times 1000 \times 0.013 = 0.39 \mu Sv$ in your lifetime.
- If you eat 30Bq of Cs137 everyday, your effective dose of Cs137 per day reaches that of potassium 40.
- Standard limits for radioactive cesium in Japan are 100 Bq/kg for foods, 50 for milk and infant foods, 10 for water.
- Standard limits for radioactive cesium in EU are 1,250 Bq/kg for foods, 400 for infant foods, 1000 for dairy products and water.
### Radionuclides

<table>
<thead>
<tr>
<th></th>
<th>I-131 Iodine</th>
<th>Cs-134 Cesium</th>
<th>Cs-137 Cesium</th>
<th>Sr-90 Strontium</th>
<th>Pu-239 Plutonium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>β, γ</td>
<td>β, γ</td>
<td>β, γ</td>
<td>β</td>
<td>α, γ</td>
</tr>
<tr>
<td>Physical half life time</td>
<td>8 days</td>
<td>2 years</td>
<td>30 years</td>
<td>29 years</td>
<td>24000 years</td>
</tr>
<tr>
<td>Effective half life time</td>
<td>8 days</td>
<td>64 days</td>
<td>70 days</td>
<td>15 years</td>
<td>197 years</td>
</tr>
<tr>
<td>Absorbed in</td>
<td>thyroid</td>
<td>whole body</td>
<td>whole body</td>
<td>bone</td>
<td>bone, liver</td>
</tr>
<tr>
<td>Radiotoxicity</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>very high</td>
<td>very high</td>
</tr>
<tr>
<td>Energy(MeV)</td>
<td>β 0.61, γ 0.36</td>
<td>β 0.65, γ 0.61</td>
<td>β 0.51&amp;1.66, γ 0.66</td>
<td>β 0.55</td>
<td>α 5.15, γ 0.05</td>
</tr>
<tr>
<td>Emitted from Daiichi</td>
<td>$150 \times 10^{15}$ Bq</td>
<td>$15 \times 10^{15}$ Bq</td>
<td>2.4 litter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Ministry of Environment publishes the amount of Sr-90 contained 0-5 cm soil of 47 points of Japan. In 2015 it was 3.9 Bq/kg at Fukushima City, 0.25 Bq/kg at Tokyo, 2.8 Bq/kg in Hokkaido. [http://www.kankyo-hoshano.go.jp/01/0101flash/01010512.html](http://www.kankyo-hoshano.go.jp/01/0101flash/01010512.html)

- Tokyo Univ team found 0.49 Bq/kg of Pu-239/240 at the Daiichi gate but not in other 17 samples. The amount of Pu-239 by Daiichi is not big as that of nuclear bomb experiments.
# Radionuclides

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Po 210 Polonium</th>
<th>K40 Potassium</th>
<th>H3 Tritium</th>
<th>U238 Uranium</th>
<th>Rn222 Radon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>α</td>
<td>β, γ</td>
<td>β</td>
<td>α, γ</td>
<td>α</td>
</tr>
<tr>
<td>Physical half life time</td>
<td>138 days</td>
<td>1,250,000,000 years</td>
<td>12.3 years</td>
<td>4,470,000,000 years</td>
<td>3.8 days</td>
</tr>
<tr>
<td>Effective half life time</td>
<td>37 days</td>
<td>30 days</td>
<td>12 days</td>
<td>variable ≤14 yrs</td>
<td>5 min</td>
</tr>
<tr>
<td>Absorbed in</td>
<td>liver, kidney, lung</td>
<td>whole body</td>
<td>whole body</td>
<td>bone, lung, kidney</td>
<td>lung</td>
</tr>
<tr>
<td>Radiotoxicity</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>Energy(MeV)</td>
<td>α 5.30</td>
<td>β 1.33, γ 1.46</td>
<td>β 0.0186</td>
<td>α 4.20, γ 0.05</td>
<td>α</td>
</tr>
</tbody>
</table>
These device measure air dose rate of gamma radiation.
These measure up to 20 to 30 microsieverts
You should keep it one meter above the ground for 30 seconds to have correct data.

Geiger-Muller (GM) tube is usually calibrated to measure mainly beta radiation of radioactive cesium in CPM (count per minute) unit.
It is used to check surface contamination
If your body shows 13,000 CPM, you should be washed.

You can check radioactivity in foods at municipal governments.
Wild mushrooms, Edible wild plants, bamboo shoots, wild chestnuts often contain Cesium 137. Beans and plum sometimes contain a slight amount of Cesium 137.
Other vegetables rarely contain cesium 137.