



*The figure in this document has been replaced to address some inquiries we received. The original picture, taken from public source, was merely meant to illustrate how the groundwater flows from the mountain side under the crippled power plant and into the ocean. The depth of the core was not in scale. Although it was not our intention, we acknowledge and regret that it caused some misunderstanding. - January 21, 2014*

## Radioactive Contaminated Water Leaks (Update)

December 2013

Even though the situation at the Fukushima No. 1 nuclear power plant remains uncertain and many years of cleaning up still lie ahead with a major impact on Japan's economy and the Tohoku population, the frequently reported water leaks do not seem to be the main concern as radiation measurements show: The influence of contaminated water is limited within the port of the NPP, an area smaller than 0.3 km<sup>2</sup>.

### Summary

- On November 14, Tokyo Electric Power Co. (TEPCO) released video footage of water pouring down like heavy rain near the containment vessel in the Reactor 1 building at the Fukushima No.1 nuclear plant. It was the first time leaks were confirmed near the three containment vessels that had experienced a meltdown in March 2011.
- The issue of contaminated water was highlighted this summer due to two incidents which raised suspicion that radioactive water was flowing into the ocean;
  - (1) the level of radioactivity detected at observation holes implied ground water was being contaminated
  - (2) a tank holding contaminated water collected from the NPP was found leaking
- No significant radioactive concentration outside the site's port has been reported. Therefore, the high level of contamination remains contained within TEPCO's site, according to government, media and researchers' reports.
- Japan has adopted the world's highest standard for limiting food and water distribution; the limit for fishery products in Japan is 100 Bq/kg-wet of Cs-134 and Cs-137, i.e. less than a tenth of EU restrictions.
- The biggest risk has been mismanagements by TEPCO and several open questions still remain; sensational reports by media have added to people's fears.

### 1. Video Footage of Water Leakage at Containment Vessel in Reactor 1 Building

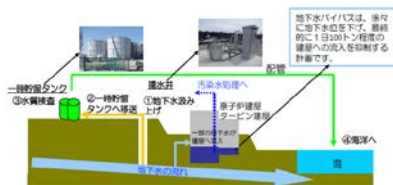
On November 14, TEPCO disclosed video footage of large amount of water pouring down near the bottom of the containment vessel in the reactor 1 building at its Fukushima No.1 NPP. One leak was confirmed coming from a rupture in a drain pipe installed at the bottom of the containment vessel and another from just above the suppression chamber connected to the containment vessel.

It is yet unclear exactly how much and from where leakage of contaminated water is occurring at the site, as the radiation level is still too high for a thorough examination of the site. The video was taken using a camera-equipped remote-controlled boat.

### 2. Contaminated Water Leakage – two incidents highlighted that raised attention

#### 1) Groundwater

On July 22, TEPCO announced it believes radioactive contaminated groundwater was leaking into the ocean because the water level fluctuation of contaminated groundwater in observation holes was seen to be linked with the tidal level. Radioactive substances had been detected in the groundwater at observation holes as early as May.



Source:  
[http://www.tepco.co.jp/nu/fukushima-np/info/images/130530\\_01s.gif](http://www.tepco.co.jp/nu/fukushima-np/info/images/130530_01s.gif)

TEPCO began taking countermeasures to prevent these waters from flowing into the ocean in late June:

- a) Injection of chemicals (liquid glass) into the ground to create impermeable wall-like structures.
- b) Cleaning and sealing trenches
- c) Construction of impermeable wall on the ocean side

Longer-term plans being considered include:

- d) Installation of impervious wall on the land side using soil freezing method
- e) Pumping up groundwater on the mountainside and discharging it to the

ocean, creating a sort of a bypass

However, these measures have faced criticisms. For example, in the case of measure (a), such walls could not be created near the ground surface, and this raised concerns groundwater could go over them and reach the ocean. The effectiveness of plan (d) has also been questioned by civil engineers.



## 2) Tank water

On August 19, TEPCO announced some 300 tons of contaminated water had leaked from its storage tanks located about 500m away from sea, through a rain drain valve of the saucer-like structure on which the tanks are placed. The reason the leakage was not discovered until after so much water had gone out was because (i) TEPCO workers had left the drain valves opened and (ii) only one water gauge was installed per five tanks. The stored water is a byproduct of cooling water still needed for cooling the reactors in order to avoid further spreading of radioactivity.

Ideally, the cooling water would be decontaminated and recycled creating a full circulating system. TEPCO can only eliminate Cesium for now. It does not help that about 400 tons of groundwater is flowing into the building each day, adding to the cooling water. Approximately the same amount is taken out of the circulating system. The bypass mentioned as plan (d) above is expected to reduce the amount of water that needs to be stored.

TEPCO is testing an additional decontamination system called the Advanced Liquid Processing System (ALPS) to take out more radionuclides including Strontium. However, ALPS encountered troubles during its test run in March 2013 and had to be suspended. The test operation was resumed on September 30 but again had to be halted temporarily in early October to apply corrosion protection measures. The test run was resumed on November 21 but will be stopped in December to confirm the effectiveness of the newly applied measures. Meanwhile, countermeasures against leakage from tanks include

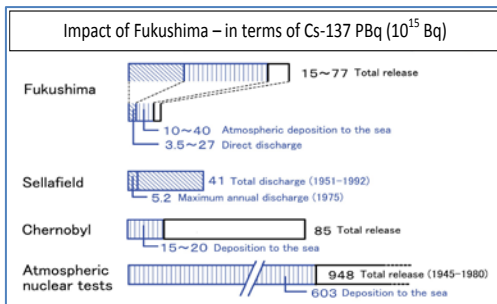
- Replacing bolted joint tanks with welded joint tanks
- Setting up monitors for each tank
- Reinforcing patrol of the tanks from two to four times a day, recording details such as radiation level in the air
- Removing contaminated soil from the area

## 3. Impact Contained on Site

- The influence of contaminated water is limited within the port of the NPP, an area smaller than 0.3 km<sup>2</sup>. Outside this port, almost all water samples are below the detection limit, according to measurements by TEPCO, the Nuclear Regulation Agency and external researchers.
- The results of monitoring of sea water in Japan are constantly below the standard of 10 Bq/l. The density limit specified by the Reactor Regulation Act is 30 Bq/l for Strontium-90 and 90 Bq/l for Cesium-137.

## 4. Comparison of the Fukushima NPP Accident with Previous Radioactive Discharges

Researchers estimate that 15 to 77 PBq (1 PBq = 10<sup>15</sup> Bq) of Cs-137 has been released to the sea and land due to the Fukushima Daiichi Nuclear Power Plant accident. This includes direct discharge as well as deposition, the majority of which occurred immediately following the accident.



The figure is comparable to past discharges from the Sellafield nuclear reprocessing site (U.K.), with a total discharge of 41 PBq, or the nuclear power plant accident in Chernobyl (Ukraine), where the total release was 85 PBq.

During nuclear testing conducted by various countries between 1945 and 1980 a total of 948 PBq of Cs-137 was released into sea and atmosphere.

The difference is even bigger for the discharge of Iodine-131 (which tends to accumulate in the body in the thyroid): 150 – 200 PBq (Fukushima) vs. 1'760 PBq (Chernobyl) vs. 675'000 PBq (Nuclear testing).

## 5. Effects on Food

Regulatory limits for fishery products	
	Cs-134 + Cs-137 (Bq/kg-wet)
Codex	1000*
EU	1250
USA	1200
Hong Kong	1000
Vietnam	1000
China	800
Singapore	500
South Korea	370
Japan	100

Japan's limit for radioactive materials in food is more demanding than that set by other countries. The limit for fishery products was lowered from 500 Bq/kg-wet to 100 Bq/kg-wet after the NPP accident.

Fishery products have been monitored since March 2011; as of the end of August 2013, 37'430 samples had been analyzed.

In Fukushima, the percentage of samples exceeding 100 Bq/kg has dropped from 53% in the period from March – June 2011, to 2.7% in the period from July – August 2013.

Suspension of fishery remains to be imposed on all coastal and bottom fisheries in Fukushima prefecture.

\*The international standard set by the Codex Committee includes S-35, Co-60, Sr-89, Ru-103, Ce-144 and Ir-192.



## 6. Mismanagement by TEPCO and Media Reports

Mismanagement by TEPCO has been a major factor for the risks involving the NPP accident. One such example is that leakage from tanks is repeatedly found; in early October, TEPCO disregarded the fact that the only water gauge for the five tanks was installed in the tank on the highest end of a slope; they poured in too much water before realizing that it was leaking from the tank on the lowest end.

Media reports are adding to the confusion. For example, the detection of maximum 1'800 mSv/h of radiation near the tanks were reported to be enough to be lethal in about four hours in prominent news outlets including the New York Times and the Guardian. While 7'000 mSv/h of exposure is indeed considered to be fatal, the articles did not explain that most of the reading was for beta radiation which travels only a short distance and that the readings less than 50 cm away from the 1'800 mSv/h spot was 15 mSv/h. The initial explanation by TEPCO did seem to have been one cause of the misunderstanding.

NY Times report "Radiation Near Japanese Plant's Tanks Suggests New Leaks"

[http://www.nytimes.com/2013/09/01/world/asia/radiation-near-japanese-plants-tanks-suggests-new-leaks.html?\\_r=0](http://www.nytimes.com/2013/09/01/world/asia/radiation-near-japanese-plants-tanks-suggests-new-leaks.html?_r=0)

Guardian report "Fukushima radiation levels 18 times higher than previously thought"

<http://www.theguardian.com/environment/2013/sep/01/fukushima-radiation-levels-higher-japan>

## Addendum

### 1. Radioactive Contaminants

Source: U.S. Environmental Protection Agency (<http://www.epa.gov/radiation/index.html>) and others

We differentiate between physical half-lives and biological half-lives. The physical half-life describes the time it takes for the amount of radioactive substance to be halved through decay, whereas the latter is the time the radioactive substance drawn into the body is halved by excretion.

The radioactive contaminants at issue are the following:

#### Cesium

Cesium is a soft, malleable, silvery white metal. Its most common radioactive form is Cesium-137. Another fairly common radioisotope is cesium-134. Cs-137 is much more significant as an environmental contaminant than Cs-134. The half-life of Cs-137 is 30 years while that of Cs-134 is 2.065 years. The biological half-life in humans is about 70 days, in fish even 30 days.

Cs-137 is one of the most common radioisotopes used in the industry. Thousands of devices use Cs-137.

- moisture-density gauges, widely used in the construction industry
- leveling gauges, used in industries to detect liquid flow in pipes and tanks
- thickness gauges, for measuring thickness of sheet metal, paper, film and many other products
- well-logging devices in the drilling industry to help characterize rock strata

Cs-137 is also used in medical therapy to treat cancer. Everyone is exposed to very small amounts of Cs-137 in soil and water as a result of atmospheric fallout.

If Cs-137 enters the body, it is distributed fairly uniformly throughout the body's soft tissues, resulting in exposure of those tissues. Slightly higher concentrations of the metal are found in muscle, while slightly lower concentrations are found in bone and fat. Compared to some other radionuclides, Cs-137 remains in the body for a relatively short time. It is eliminated through the urine. If exposures are very high, serious burns, and even death, can result. Instances of such exposure are very rare.

#### Iodine

Iodine is a nonmetallic solid element. There are both radioactive and non-radioactive isotopes of iodine. I-129 and I-131 are the most important radioactive isotopes in the environment. Some isotopes of iodine, such as I-123 and I-124 are used in medical imaging and treatment, but are generally not a problem in the environment because they have very short half-lives.

Iodine-129 has a half-life of 15.7 million years; iodine-131 has a half-life of about 8 days. Both emit beta particles upon radioactive decay. Iodine has a biological half-life of about 100 days for the body as a whole.

#### Strontium

Strontium is a soft metal similar to lead. Sr-90 has a half-life of 29.1 and a biological half-life of about 18 years. Sr-90 behaves chemically much like calcium, and therefore tends to concentrate in the bones and teeth. Internal exposure to Sr-90 is linked to bone cancer, cancer of the soft tissue near the bone, and leukemia. Large amounts of Sr-90 were produced during atmospheric nuclear weapons tests conducted in the 1950s and 1960s and dispersed worldwide.



## Tritium

Tritium is a hydrogen atom (that has two neutrons in the nucleus and a single proton) and readily forms (tritiated) water when exposed to oxygen. It has a half-life of 12.3 years and a biological half-life of about 10 days. As with all ionizing radiation, exposure to tritium increases the risk of developing cancer.

Tritium is one of the least dangerous radionuclides since it emits very low energy radiation and leaves the body relatively quickly; once tritium enters the body, it disperses quickly, being uniformly distributed throughout the body and then excreted through the urine within a month or so after ingestion.

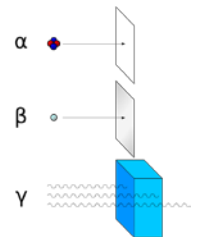
## 2. Radioactive Decay

**Radioactive decay (nuclear decay or simply, radioactivity)** is the process by which an unstable atomic nucleus emits subatomic particles, i.e. it loses energy by emitting particles of ionizing radiation. A material spontaneously emitting this kind of radiation—emitting therefore energetic alpha particles, beta particles, or gamma rays—is considered **radioactive**. There are many different types of radioactive decay:

- **Alpha-decay** occurs when the nucleus ejects an alpha particle (helium nucleus).
- **Beta-decay** occurs when the nucleus emits an electron or positron and a type of neutrino, in a process that changes a proton to a neutron or the other way around.
- **Gamma-decay** occurs after one of the other two forms of decay (alpha or beta) has occurred; it produces gamma rays (or gamma radiation) which is electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous. Gamma rays can be produced by a variety of phenomena of which gamma-decay is one.

The rays were given the alphabetic names alpha, beta, and gamma, in the order of their ability to penetrate matter.

At a cellular level, the damage caused by ionizing radiation is similar. However, because rays of alpha particles and beta particles are relatively non-penetrating, external exposure only causes localized damage, e.g. radiation burns to the skin. Gamma rays are more penetrating, causing diffuse damage throughout the body rather than burns. Furthermore, we should distinguish external radiation exposure from internal exposure, due to ingested or inhaled radioactive substances. Depending on the substance's chemical nature, internal exposure can produce both diffuse and localized internal damage.



## 3. Units of Radioactivity Measurements

The SI unit of radioactive activity is the **Becquerel (Bq)**, in honor of the scientist Henri Becquerel. One Bq is defined as one decay (or transformation) per second. Since a sensible size of radioactive material contains many atoms, a Bq is a tiny measure of activity; amounts giving activities on the order of giga- (GBq,  $10^9$ ), tera- (TBq,  $10^{12}$ ) or peta- (PBq,  $10^{15}$ ) Becquerel are commonly used. So if a radiation detector (for example, a Geiger counter) detects the radiation of one decay coming from a sample in one second, then that sample would be said to contain one Becquerel of radiation. A sample emitting radiation from one hundred decays per second would be said to have a radioactivity of 100 Bq.

The Becquerel is used to measure the amount of radiation emitted by a substance but it does not tell the effect of that radiation on the human body. To understand its effects we need to measure the amount of energy from the radiation being absorbed by the body; this is measured in joules per kilogram. The absorbed dose alone does not indicate how much damage is done to the body, because different types of radiation cause different amounts of damage. The absorbed dose is therefore multiplied by a weighting factor (1 for beta and gamma radiation, and 20 for alpha radiation). The result is called equivalent dose and it is expressed in **Sieverts**. This is essentially a measure of the amount of potential damage to the body from a given amount of radiation. Since one Sievert is very large, we usually hear of the much smaller mSv (millisieverts,  $10^{-3}$  Sv) or  $\mu$ Sv (microsieverts,  $10^{-6}$  Sv).

Sieverts can be used to express the total or accumulated equivalent dose, which is useful to talk about a one-time exposure, or a person's lifetime dose. Often we use the dose rate or the equivalent dose over a certain period of time; in that case the dose rate is expressed in Sv/h or Sv/year. One Sievert carries with it a 5.5% chance of eventually developing cancer. Doses greater than 1 Sievert received in a short time period likely lead to radiation poisoning and possibly to death within weeks.