Preface

In March 2011, many regions of Fukushima Prefecture were contaminated with radioactive cesium due to the nuclear accident triggered by the Great East Japan Earthquake. As a scientist who specializes in soil physics, I was deeply concerned about the pollution of farmland. I was worried that the agricultural products would be contaminated if no action was taken. Therefore, I focused my research on the relationship of soil particles and the adsorption characteristics of radioactive cesium. We developed a simple soil decontamination method that can be done by anyone. However, to decontaminate soil, it is necessary to correctly understand the adsorption characteristics of soil and radiation, and understand the science behind the decontamination method which is difficult to understand if not simplified.

The United Nations designated 2015 as the International Year of Soil and this led to a better understanding among the general public about the importance of soil. In that year, I asked my ex-students working at universities (young scientists who are the members of the Soil Physics Research Group of the Japanese Society of Irrigation, Drainage and Rural Engineering) to provide an educational program that elementary school students can participate in and enjoy understanding the nature of soil (clay) through experiments. At elementary schools and science museums in Fukushima Prefecture, we began to deliver a lecture called "Dr. Doroemon's Class on Soil, the Magician!" And parents and teachers at elementary schools said, "We want more teaching materials to be available at elementary schools ". So, we thought about a curriculum together and came out with a book. We decided to publish this book with the cooperation of Toho News Service.

This is a picture book for children with commentary for parents. We hope that the simple experiments and explanations introduced in this book will allow more people to have a better understanding about the relationship of soil adsorption characteristics and radioactive cesium, and use it as a powerful resource for local revitalization.

* The lecture was conducted as a part of the project "Building and deploying a public-private academic collaboration network through reconstructive agriculture" funded by the JST (Japan Science and Technology Agency) Organization Collaboration Promotion Network Formation Project as in Science and Technology Communication Promotion in 2014.

What is "Cesium" and "Radiation"?

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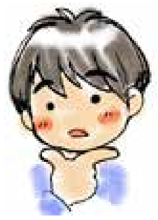
It sounds complicated, but let's learn more together through this picture book!

I often hear and see the words "cesium" and "radiation" on television and in newspapers, but what is it all about? I want to know more but it sounds so complicated!

I will help you, so let's learn together!

Dr. Doroemon

University professor who studies soil.
Good at making soil dumplings.

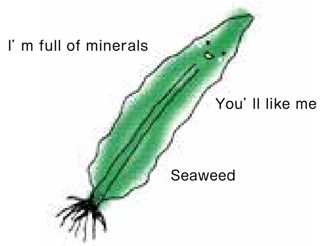


Where is the radiation found?

There are various places it is emitted (coming out) from and it is useful for many things.

So, what is all the fuss about?

There are many people who are worried because radiation cannot be seen, but it is actually emitted from a lot of common things around us!



Radiation dose in our daily life

Radiation around us	Radiation dose（mSv）
Natural radiation in Guarapari（Brazil）	10（1 year）
CT Scan（Computed tomography examination）for chest	6.9（once）
Natural background radiation（average value in the world）	2.4（one year）
General public dose limits（excluding medical exposure）	1（one year）
Stomach X-ray	0.6（once）
Tokyo to New York by air travel	0.2（one round trip）
Chest X-ray	0.05（once）

Radioactivity of foods containing Potassium-40

Examples of foods containing Potassium-40	Radioactivity（Bq/kg）
Dried shiitake	700
Raw wakame	200
Spinach	200
Beef	100
Fish	100
White rice	40

Source: HIROSHIMA Prefectural Medical Association (http://www.hiroshima.med.or.jp/pamphlet/245/2-2.html)

There is radiation around us

A different unit of radiation is used depending on the purpose. “Sievert (Sv)” is the amount of radiation received by a person and “Becquerel (Bq)” indicates the intensity of radioactivity (→p.9) emitted by a substance.
We are subjected to radiation from space, the earth, the air, and we receive about 2.1 mSv (Japan average) of natural radiation annually. In addition to that when we go to higher altitudes such as when we fly from Tokyo to New York, we are subjected to higher amounts of natural radiation from space, and as we go higher in altitude, the radiation dose from space increases. We also absorb 0.2mSv of radiation in the form of Potassium 40, a kind of mineral present in food. Examples of foods high in this form of potassium include dried kelp (2,000 Bq/kg), dried shiitake (700 Bq/kg) and potato chips (400 Bq/kg). In addition, in modern times, we are also exposed to several sources of artificially created radiation such as radiation from medical treatment, where a patient receives about 0.05 mSv of radiation from a chest X-ray as an example.

Does it have anything to do with the earthquake?

At the time of the Great East Japan Earthquake in 2011, there was an accident at the Fukushima nuclear power plant and Cesium-137 came out.

What happened at the Great East Japan Earthquake?

An accident happened at a nuclear power plant in Fukushima, and a lot of “radioactive material” popped out.

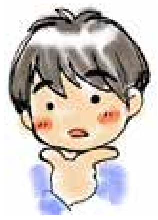
Results of aircraft monitoring by MEXT and US Department of energy（Total amount of cesium 134 and 137 accumulated on the ground surface）

Source: Nuclear Regulatory Commission HP. Published on April 5th, 2011.
(http://radioactivity.nsr.go.jp/ja/contents/4000/3710/24/1305820 20110506.pdf)

The problematic substance that escaped at the time of the nuclear accident was Cesium-137.

A large amount of radioactive substances (→p.9) leaked out of the Fukushima Daiichi Nuclear Power Plant following the Great East Japan Earthquake on March 11, 2011.

The released radioactive substances were carried by the wind and fell on the ground with rain and snow. It has been confirmed that the radioactive substances released in the accident contained Iodine (Iodine-132 and Iodine-133), Cesium (Cesium-134, Cesium-137), etc. Among them, radioactive cesium (Cesium-137) has a major impact on the environment. This is because the half-life (→p.13) is about 30 years, which is longer than other radioactive substances released at the same time.

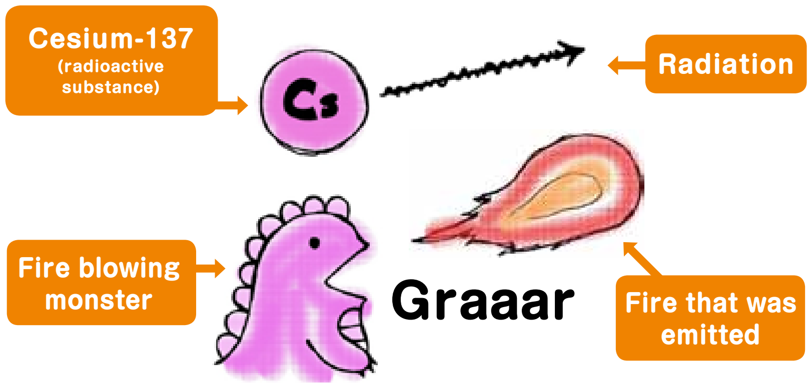


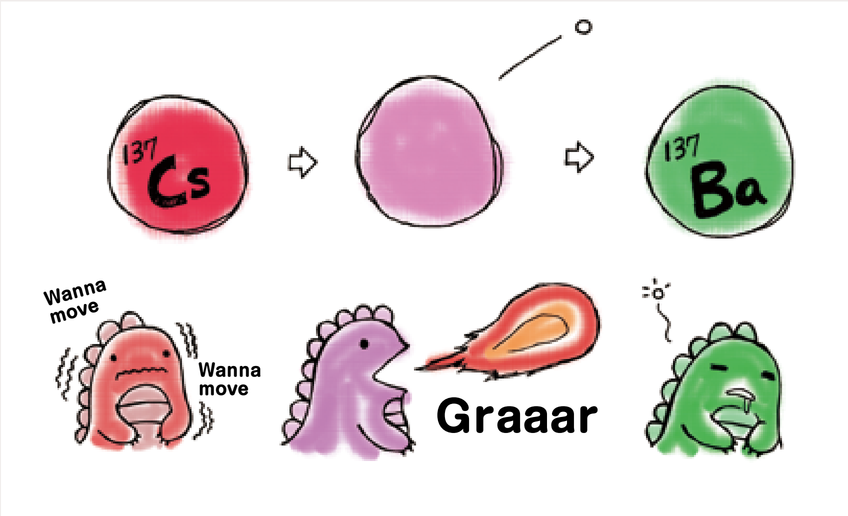
Radioactive substance?

A substance that emits radiation is called a radioactive substance. A radioactive substance will become stable after it emits radiation.

Are radioactive substance and radiation the same thing?

Imagine a fire blowing monster.
If the radioactive substance is the "fire blowing monster", then radiation is the "fire".
Radiation damages the cells in our bodies.





What is a radioactive substance?

Everything around us is made of many small particles called atoms. The substance released in the accident at the Fukushima Daiichi Nuclear Power Station contained "radioactive cesium" atoms. Radioactive cesium spontaneously breaks down into another atom called barium and when the atom breaks down, radiation is emitted. Substances that emit radiation in this way are called "radioactive substances". The barium produced by the destruction of radioactive cesium is stable and does not emit any more radiation.

If the number of radioactive atoms (for example radioactive cesium) in a substance is large, the number of atoms that can be destroyed will increase, and the amount of radiation emitted will increase. The strength of radiation emission is called "radioactivity" and is expressed in units of "Becquerel (Bq)" (→p.5). Bq indicates how many radioactive atoms breaks in one second.

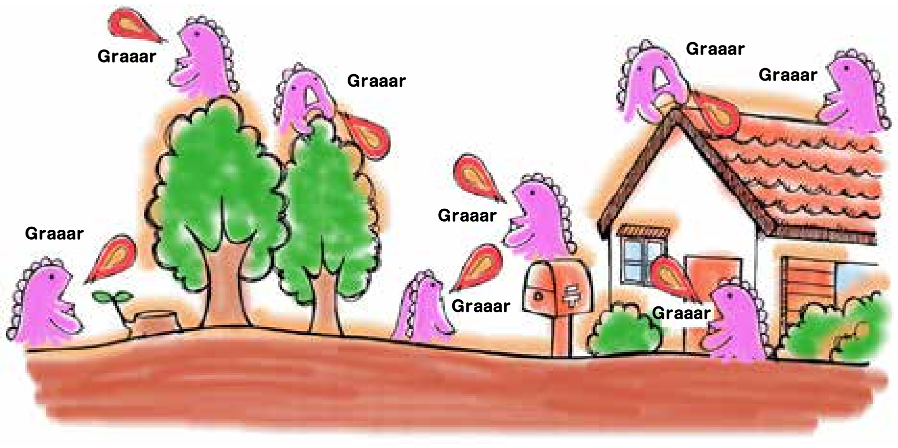
There are several types of radiation rays, including alpha (α-rays), Beta (β-rays), Gamma (γ-rays), and X (X-rays). Radioactive cesium emits β-rays and γ-rays. Compared to α-rays and β-rays, γ-rays and X-rays have more penetration power to pass through substances (→p23).

Reference: Supervised by Tetsuo Usuda, "You can see with your eyes" Radioactivity and nuclear power plants". (Sougyou-sya)

Where are fire blowing monsters?

After falling from the sky, They are hiding on the surface of various things.

Where are fire blowing monster stayed outside?



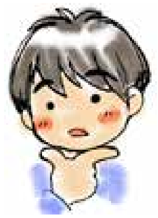
After being popped out in the atmosphere, fire blowing monsters (radioactive Cesium-137) floated in the air and fell on the ground and roofs of houses. Then they blew more fire (radiation).

Automatic measuring system for air dose in forests

Cesium is in various places and emits radiation

Radioactive substances, such as radioactive cesium and radioactive Iodine, released in the nuclear power plant accident have entered the forests, fields, houses and other places. After the accident, the effect of radioactive Iodine has disappeared, but radioactive cesium sticks to houses, soil, plant foliage, and continues to emit radiation. However, since cesium itself is not a gas, it is not floating in the atmosphere although it sometimes sticks to the fine dust particles in the atmosphere. Also, there has been no natural increase in radiation dose in the atmosphere since the accident. Therefore, it is effective to know points where the dose is high on the ground and decontaminate them.* Because cesium sticks to dust on roofs of houses and on the ground outside, the radiation dose from cesium is higher outside than inside of the house. In addition, it is higher at the closer place to the surface ground than the place far from the surface ground.

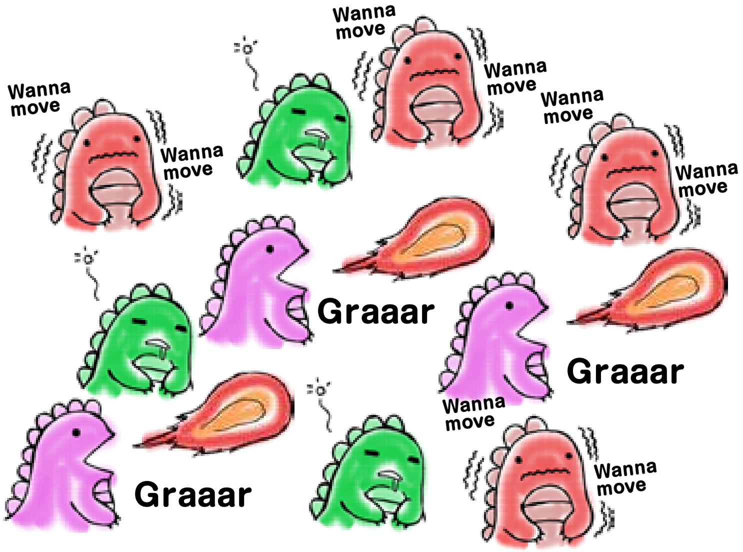
*Even now, researchers are measuring changes of radiation dose in fields and forests, and investigating effects of decontamination.

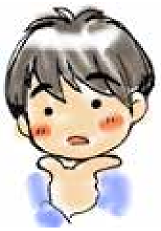


How long will monsters stick around?

After 30 years, half of them will disappear.
After 100 years, the number will be one-tenth of today.

Fire blowing monsters (Cesium-137) become harmless monsters (another substance) when they blow out fire. It will take 30 years for half number of monsters blow fire.





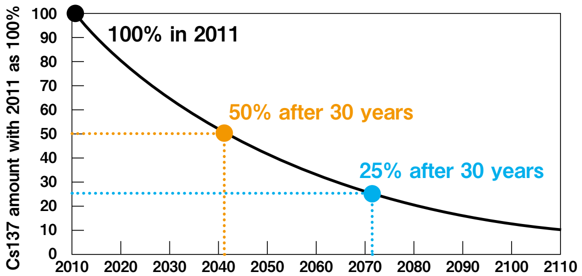
Whoa! 30 years?! It is a long-term problem to be worked on until we become adults.

Half-life of major radioactive substances

	Radioactive substance	Half life
	Iodine-131 (131I)	8.0 days
△	Cesium-134 (134Cs)	2.1 years
	Strontium-90 (90Sr)	28.8 years
○	Cesium-137 (137Cs)	30.1 years
	Radium-226 (226Ra)	1,600 years
	Plutonium-239 (239Pu)	24,000 years
	Uranium-238 (238U)	4.5 billion years

*Emissions of other radioactive substances are extremely small compared to cesium

The amount of cesium-137 predicted from the half-life



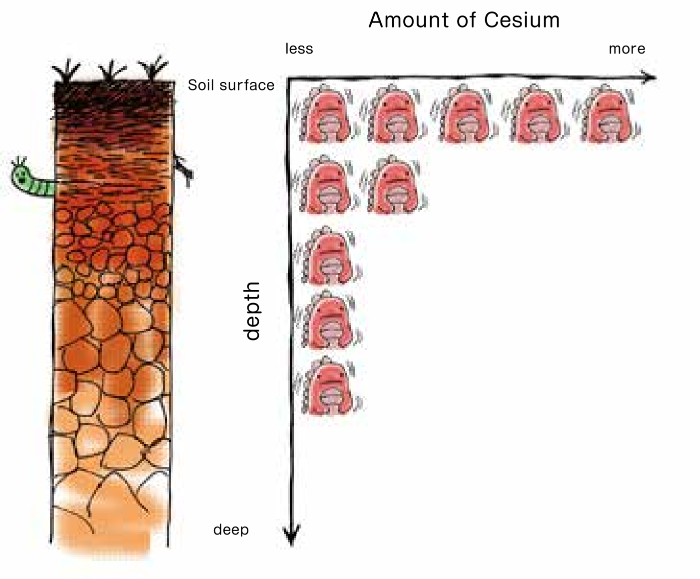
Half-life: The time required for radioactivity reduces to half

Once a radioactive substance emits radiation, it changes to a different substance. The time it takes for half the amount of one radioactive substance to change to a different substance is called the “half-life” . The half-life of radioactive Iodine (Iodine-131), which was noticed at the time of nuclear power accident, is 8 days. As a result, the number was reduced relatively quickly after the accidence, and in 16 days it reduced to 1/4th and in two months it became less than 1%. On the other hand, the half-life of Cesium-137 is about 30 years. If decontamination is not performed, more than 90 % of 2011 remains even after 5 year passed. more than 90% of the amount present at the time of accident will remain. It takes about 100 years to reduce it to 10%, so it is necessary to address the issue in the long term. In addition, compared to the amount of cesium, the amount of other radioactive substances released is incredibly low and hence can be safely ignored.

Fire blowing monsters stay in soils?

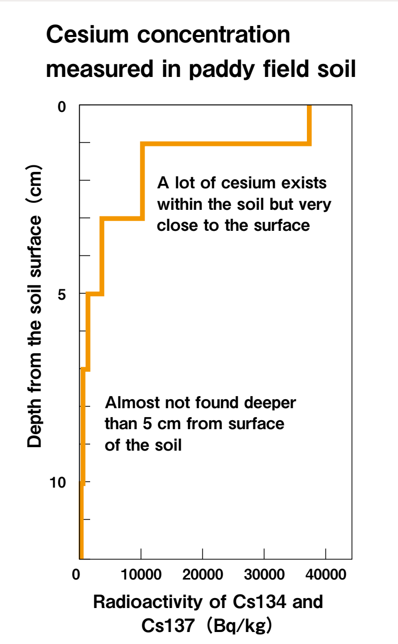
They are hiding in soils close to the surface, but not in deep.

What happened to the cesium that fell to the ground?



From our measurement, Cesium was found only between the soil surface and 5 cm depth.

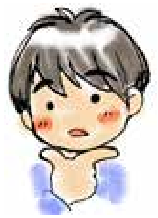
Picture of soil sampling
(October 2012, paddy field in Sasu area, Iitate village, Fukushima)



Source: Shiozawa et al., "Vertical Concentration Profiles of Radioactive Caesium and Convective Velocity in Soil in a Paddy Field in Fukushima". Radioisotopes journal, Issue of August, 2011.

Where does the Cesium that fell on the ground go?

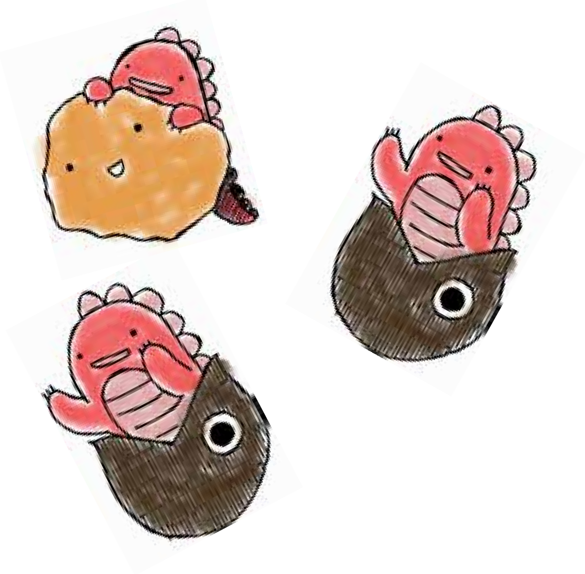
After the accident, on May 24th, 2011, soil was sampled from paddy fields in Fukushima prefecture and the amount of radioactive cesium was measured. As a result, it was found that most of the radioactive cesium that had fallen was detected above 5 cm depth, and could not be detected in deeper soils. Usually substances spread on soil like fertilizers dissolve in the rainwater and flow deeper underground. However, the soil of the paddy field binds cesium more strongly than other substances, e.g. potassium, by adsorption power. Of course, these cesium bound soil particles also flow with rainwater, but they will be caught in the pores of the soil and do not flow deep into the ground (filtration effect). We will explain the power of soil called "adsorption power" and "filtration effect" from the next page.
However, there are reports that cesium is found deeper in places excavated by wild animals such as boars.



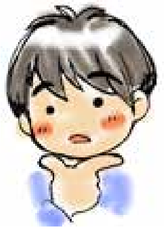
Why is it only found near the surface of soil?

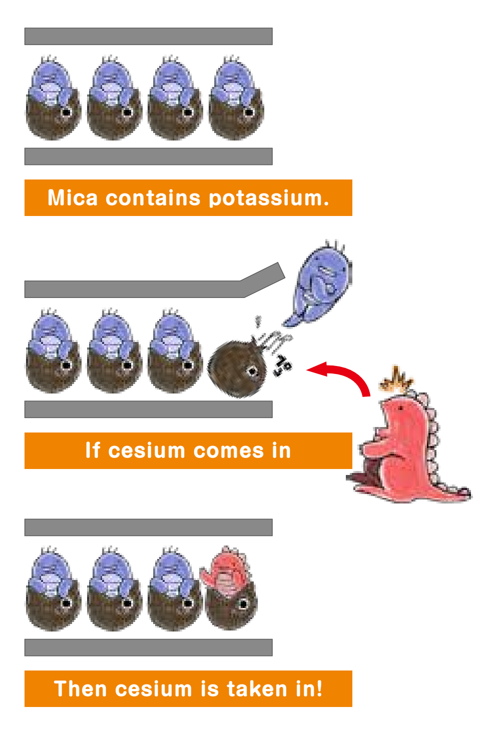
Because the soil has a magical “magnetic” power for cesium

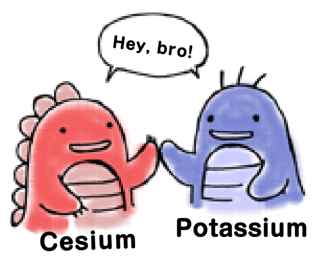
A small piece of soil has the power to attract cesium. This is called the “adsorption phenomenon”.



Once soil and cesium get attached to each other, cesium cannot get away from the soil.







Cesium and potassium are very similar

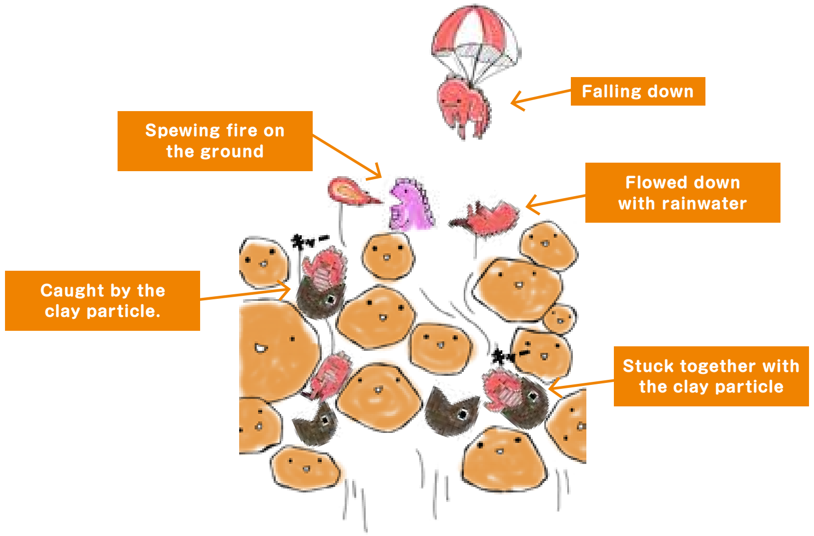
About the special power of soil to adsorb radioactive substance

Clay particles play an important role in the adsorption power of the soil. Clay is a soil particle smaller than 0.002 mm in size, produced when rocks are crushed over a long period of time (physical weathering) with gradual dissolution and alteration by water (chemical weathering). Such clay is important for the process of decontamination. The clay surface is negatively charged and has an adsorbing power to attract positively charged ions such as cesium and/or molecules .
The above kind of mica (vermiculite and illite) strongly adsorbs to cesium in soil because of its special adsorption power. Weathered mica has a layered structure in which potassium is bound like a sandwich. When cesium whose chemical characteristics are similar to potassium approaches near its surface, it replaces potassium and enters between the layer to form a stable structure. It is known that there are many vermiculites and illite in the Abukuma Mountains in Fukushima Prefecture.

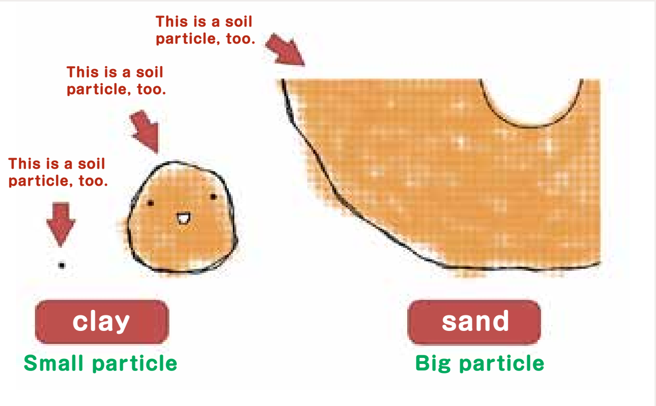
Don't such soil particles flow deeper in the soil with the rain?

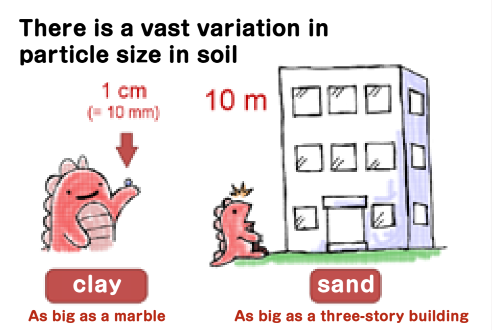
This is also a mysterious power of the soil.
Let's look more into the soil!

Soil particles bound with cesium get stuck in the soil pore of the particles and are unable to move. This power of the soil is called the "filtration effect".



Ah! I see, that's why even when it rains the clay particles with cesium do not flow deeply.





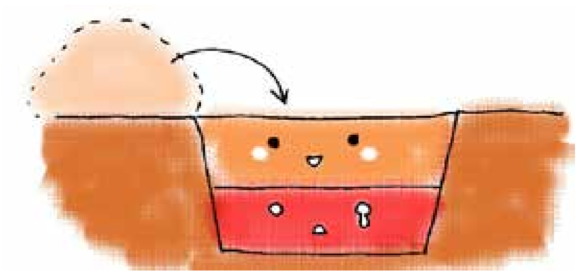
There is a large variation in soil particle size

Soil particles are classified into the following 3 types: clay (smaller than 0.002 mm in diameter), silt (0.002～0.02 mm in diameter), and sand (0.02～2 mm in diameter). If a clay particle was as big as a marble, a sand particle would be as big as a three-story building. Thus, soil consists of several kinds of soil particles in different sizes along with organic matter. These contents such as clay, silt and sand particles make a variety of pores in soil. The filtration effect of soil is a phenomenon that particles get stuck in the mesh-like soil pore. The small pores can be less than 0.001 mm in diameter, so even clay particles that flow with water are trapped in the smaller pores and remain in the soil.

What are we to do with the contaminated soil?

Stripping and burying the soil will protect you from radiation.

It's only soil on the surface, so should I strip it?

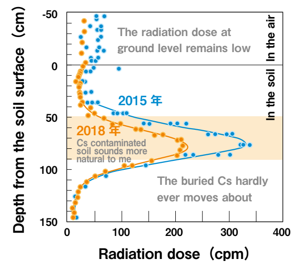


Instead of collecting and putting them in a bag, there is also a way to bury them deep in the ground.

Burying Experiment of Contaminated Soil

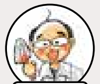
Radiation dose when Burying Cesium-Contaminated Soil

*cpm is the displayed value on the radiation measuring device



Source: Mizoguchi (2018)「Does radiocesium leak out from contaminated soil buried in a paddy field in Iitate Village?」Annual Conference of Irrigation, Drainage and Rural Engineering

Does cesium contamination disappear by bagging it or burying it deep in soil !?



The Ministry of Agriculture, Forestry and Fisheries has recommended three methods of decontaminating agricultural land, according to the degree of radioactive cesium contamination. Stripping topsoil (if containing 10000 Bq / kg or more), muddy water removal (if containing 5000-10000 Bq / kg), and reversal tillage (if containing 5000 Bq / kg or less). However, the method used most frequently was stripping topsoil. The contaminated topsoil was collected by stripping away the top layer of soil and putting the topsoil into giant 1 m3 flexible container bags (Flexi-con bags) used for packing bulk soil or similar material. Then, the filled flexi-con bags were transported and stored (~4 to 5 tiers high) at temporary storage sites. At each site, other flexi-con bags filled with uncontaminated sand were placed along the sides of the bags containing contaminated soil to reduce the radiation dose (→p .23 Shielding). Such flexi-con bags were piled up in large quantities at the temporary storage sites, but they are gradually being removed to the intermediate storage sites.

On the other hand, reversal tillage (plowing to replace surface soil with subsoil) is a method in which the upper and lower soils are inverted using agricultural machinery and the contaminated soil is buried deep within the same sites. If this method was used according to the criteria by the Ministry of Agriculture, Forestry and Fisheries, the volume of contaminated soil in flexi-con bags could have been significantly reduced. However, it was rarely adopted due to the concerns that radioactive cesium remaining in the ground would move underground and contaminate the groundwater.

Dr. Doroemon actually buried the contaminated soil at a depth of 50-90 cm underground and put uncontaminated soil over it. Even now, we regularly measure the radiation dose at various depths, but we confirmed that the buried radioactive cesium does not move and that the radiation dose at ground level remains low (upper right figure).

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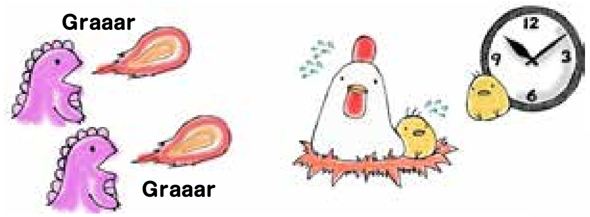
How can we protect ourselves from radiation?

There are three ways to protect
yourself from radiation!

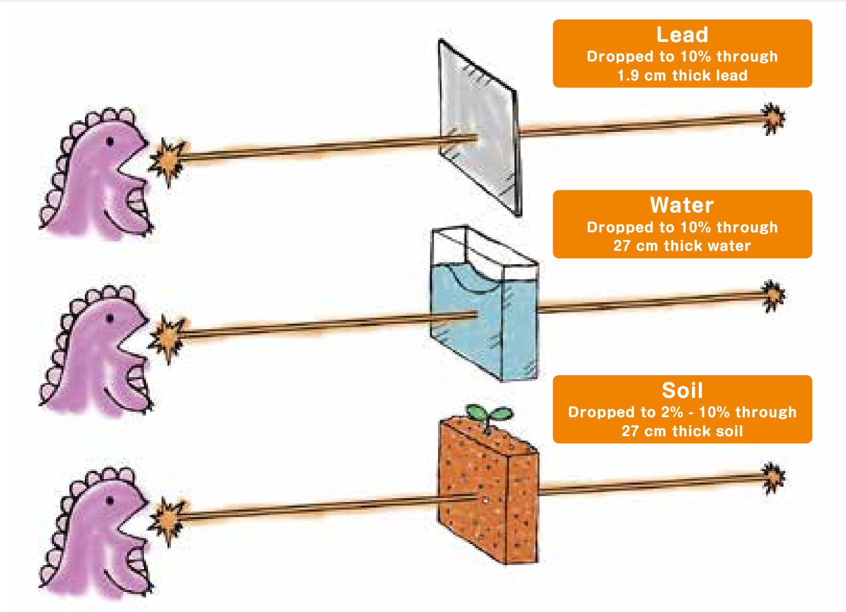
Take care of the following 3 things:

Stay away from radioactive substances



Shorten the exposure time to radiation

Enclose radiation in a box



Three Ways to Protect Yourself from Radiation

Distance

Light and sound reduces in intensity with increasing distance and therefore it becomes darker and quieter with increasing distance from source of the sound or light. Similarly, radiation also weakens in intensity with increasing distance from the source of the radioactive substance. The intensity of radiation is inversely proportional to the square of the distance from the radiation source (radioactive substance)

Time

In a cold storage room(-18℃), if you stay for short time, you don' t feel so cold but if you stay for a longer time then you will freeze. Similarly, the shorter the time of exposure to radiation, the smaller the radiation dose.

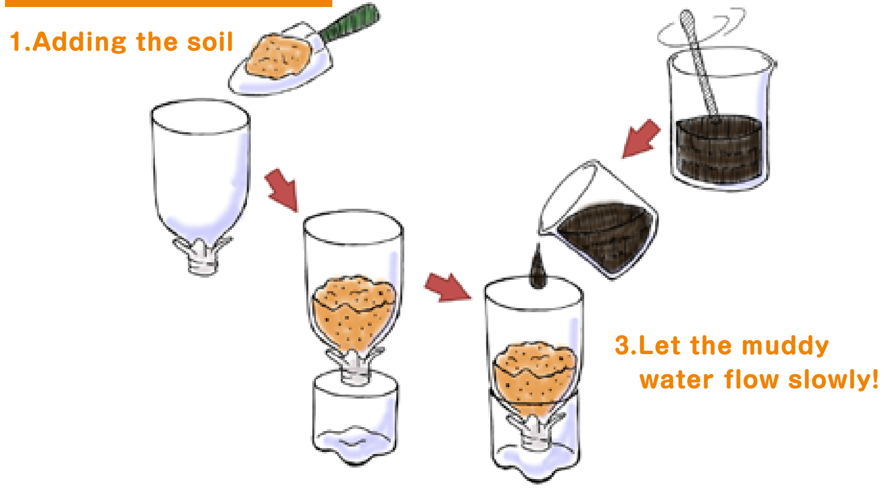
Shielding

When an object blocks sunlight, the intensity of the light will be reduced. Similarly, when an object blocks radiation, the amount of radiation released will be smaller. Also, a thin object such as single sheet of paper will not block the light, but hundreds of sheets together will block the light. Similarly, shielding effect from radiation will be different depending on the thickness and type of the shield.

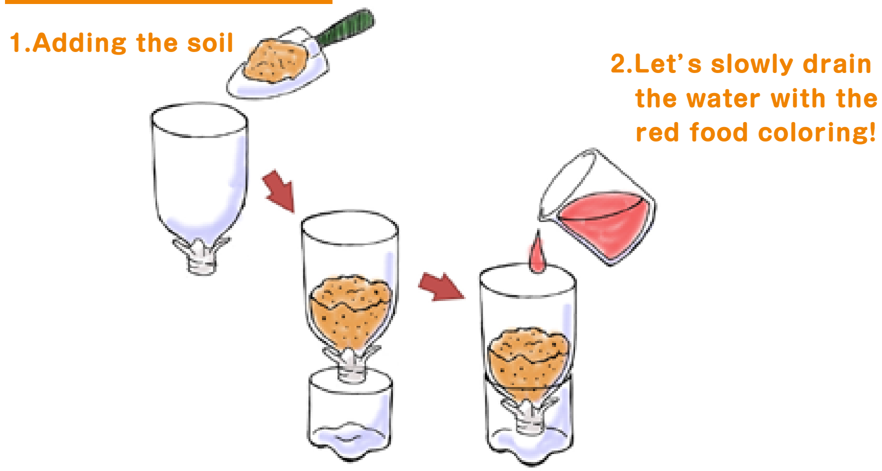
Experiment: Soil is a magician!

Let' s explore the mystery of the soil using an experiment using a plastic bottle.

Let's see the filtration effect



Let' s look at the adsorption phenomenon.



Adsorption experiment using plastic bottles
(from left: field soil, mountain soil, sea sand, sawdust)

An Experiment Shows the Flow of Water and the Role of Soil

With a rubber band, tie a gauze mesh around the mouth of the plastic bottle which is cut in half. Use a fine gauze mesh that does not allow soil particles to pass through or use two layers of gauze.

While putting soil into the plastic bottle if you press down and pack the soil too hard, the pore between soil particles will become too small and it will make it difficult for water to flow through. The experiment can be repeated several times, but if it is done too many times, fine soil particles will fill the soil pores of the soil filled in the bottle, or the soil will become too compacted due to the weight of the water. In such case, please replace the soil in the plastic bottle. If you look closer, you will see that clay particles are gathering around the top of the soil surface which slows down the flow of the water. This phenomenon is called cake filtration.

It is advisable to dye the water with thin ink for the adsorption experiment. If it is too thick, then there may be pigments that exceed the adsorption capacity of the soil and it may be difficult to distinguish the color of the water that comes out. In the case of sand, reddish or muddy water flows out as it is, and in the case of soil from the field, the water that flows out is nearly colorless (transparent) or faded out.

Did you understand how the soil affects radioactive substances?

The soil has the important power to protect us from radiation.

I now know about radioactive substances and the power of soil.

It is important to understand radiation properly and protect ourselves.

In conclusion

A radioactive substance decreases year by year, but the rate of reduction slows down gradually. Cesium-137 has a long half-life of 30 years and must be dealt with for a long time.

We conducted a soil experiment in the classroom of elementary school and at a science museum in Fukushima prefecture to let the children experience the soil adsorption phenomenon and the filtration effect. The purpose is to bring up children who properly understand the behavior of radioactive cesium adsorbed on the soil and form their own opinion about it and think independently. I decided to publish this teaching material to be used in lecture because I wanted everyone across the country to know about the magic of the soil.

We hope that both children and parents will read this book, conduct experiments, and correctly understand the relationship of soil adsorption properties and radioactive cesium. Radioactive cesium contamination cannot be resolved easily, but there is no need to panic. We believe that facing reality is the first step in solving a problem. I hope this book can help you a little.

Masaru Mizoguchi, aka Dr. Doroemon
Professor, Graduate School of Agricultural and Life Sciences, The University of Tokyo.

<Dr. Doroemon and his friends>

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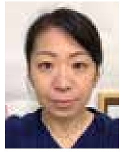

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