Gerhard Proehl:

Okay. Thank you very much. Good afternoon, ladies and gentlemen. I will talk now a little bit about nuclear accidents which happened in the Chernobyl nuclear power plant and in the Fukushima Daiichi Nuclear Power Station. Let us remind the releases to the terrestrial environment via Chernobyl and Fukushima and the main radionuclides are iodine 131, cesium 134 and 137, strontium has some relevance in Chernobyl but little relevance in Fukushima and xenon 133. They were also large amounts released. Here, we have the deposition of cesium 137 in Ukraine and Russian Federation and Belarus and it's a comparison with Fukushima. You see the maximum levels both in Fukushima and in Chernobyl are similar. However, in Chernobyl larger area has been affected. So what happened in Chernobyl? This Chernobyl Unit 4 reactor started operation in 1983 and in 19 April 1986 some tests were done on the cooling system Unit 4.

This experiment, this test, went out of control. And then it was tried to shut down the facility. However, it did not because it was a failure and some seconds later the reactor ran out of control and exploded. Over a period of 10 days, large amounts of iodine 131, iodine 133, tellurium 132 and cesium 137 have been released. And the releases went on about 10 days on the beginning of May the main release in the beginning [ph] of May. So the emergency measures taken were evacuation, bring people away, application of stable iodine, this is because iodine is readily taken up by the thyroid and may cause pretty high thyroid doses. And if stable iodine is applied in large amounts before the intake of radioactive iodine then the thyroid is some kind of saturated and the uptake of radioactive iodine will decline considerably. And we have food restrictions, decontamination surfaces and relocations, this means bring people away to other areas.

So the early measures taken were in the morning of 26th April, the town of Pripyat at a distance of about 3 km from the Chernobyl nuclear power plant. There was instruction to remain indoors, close the doors and windows and see those rates started rising. The next day those rates reached 10 mSv/h and evacuation of 45,000 people started in Pripyat. On 7th of May about 100,000 people were evacuated from 76 settlements in a radius of 30 km and the Chernobyl exclusion zone was established with a radius of 30 km and this exclusion zone still exists.

In 1986, we had about 116,000 people (0:05:00) evacuate in total. And what is beyond 1986 about 220,000 people were really relocated from areas outside the Chernobyl

Exclusion Zone. So the measures taken to reduce internal exposures is the application of stable iodine started already in the 26th of April. This was the day of the accident and it's important that it starts as early as possible and about more than 5 million people got stable iodine in USSR.

But it was obviously no systematic distribution. Food restrictions came into play in particular restriction on grazing and use of fresh fodder to reduce thyroid doses. This is in principle very effective if it's applied immediately. However, there was the former Soviet Union the implementation of early countermeasures was a bit delayed. It was also delayed information of the population about the accident and so private farmers continued to consume fresh milk and green vegetables which caused via from by other pathway, pasture, cow milk, high doses to thyroid which could have been avoided. When you look on the areas affected from the Chernobyl accident. This is the deposition in kBq/m2 and in total we have affected [ph] area of about close to 150,000 square kilometers. Areas were at deposition below 37 kBq/m2 were considered as not contaminated. So also in the USSR there were criteria for remediation were enforced. And there was a change of these criteria with time.

The first criteria in 1986 [ph] was 100 mSv as a temporary limit for the average equivalent whole body dose for the period for the first year from 26 April 1986 to 26 April 1987. So 100 mSv for the first year, 30 mSv for the second year and 25 mSv for the third, the fourth year this is 89 and 90. From 1991, new levels were enforced by Belarus, the Russian Federation and Ukraine. The USSR separated in 1991. And these are one of the states which were formed in this period. Then the intervention level was 1 mSv per year for post emergency situations. And if this level is exceeded, this could mean that remediation measures have to be implemented to reduce this to less than 1 mSv per year. And 1 mSv per year has also been chosen by the Japanese government in 2011 as a long term goal. This is the effected population groups and doses received. This is what we can see here.

There are different groups. These are the operation workers (liquidators) from 1986 to (0:10:00) 1990. These were people who were involved in cleanup in collecting fragments, cleaning up the area, et cetera., and in total there were 530,000 people were involved in this work. We have about 115,000 people evacuated and more than 200,000 people in the areas of strict control where cesium levels larger than 555 kBq/m2. This number is equivalent to 15 joules [ph] it is the same as 555 kBq/m2. That's why we have this it's not a round number and in total more than 6 million people lived in areas with contaminations

higher than 37 kBq/m2. Okay. A huge program was initiated first in the USSR and later on in the three most effective states, Russia, Belarus and Ukraine to reduce exposures from radio cesium. This work focused first on residential areas with emphasis given on school, kindergarten and public buildings. And most was washing buildings with water or special solutions, cleaning of residential areas and roads or removal of contaminated soil.

Agricultural land there was a wide range of measures starting with ploughing this mean turning the upside down and putting if you have a special plougher then you can sort of put the surface to the depths of 20 or 30 cm depending on the plow. Then food restrictions were implemented, especially for milk and meat. Then the treatment of pasture in particular for some kind of pastures which were not very, very intensively managed and they will then improve by ploughing, re-seeding, having k fertilizer, potassium fertilizer and lime to increase the pH value. Other one is using clean fodder. This is the obvious countermeasure and also to apply cesium binders. This is Prussian Blue. Prussian Blue is a compound that selectively absorbs cesium ions in its crystal lattice and it's ammonium hexacyanoferrate and small amounts of this Prussian Blue of 10 g for a cow cause a reduction of factor of three to five in milk.

So it's a very effective measure. There's one little disadvantage. It is blue, a deep blue compound, it is not toxic. No it is not toxic but it also used for example in for humans if people have incorporated too much cesium 137, maybe workers, they got this Prussian Blue and the excretion is accelerated by a factor of two. So it's not this is a stable ___ compound. It is not toxic; however, it is blue and the Prussian Blue not all people like it but it's effective. So I mean (0:15:00) some of these measures to reduce cesium 137 in crops and animal products are still going on in some areas. Also in some freshwater bodies, we had restriction on drinking water and consumption of freshwater fish. This is easy. Other countermeasures were applied but they were in general ineffective and not sustainable. So this is an example of the decontamination of settlement. You see here cleaning the roof, removing the upper part of the soil, the upper part of lawn. Here you also this is everything is very time consuming and hard work.

Okay and then let’s so come to Fukushima. This happened in 2011. So there was this earthquake in the Pacific Ocean causing a tsunami causing huge wave and this wave touched the shore on the east side of Japan. And you see here it is run-up height of the wave so it is enormous and I mean you all know that 20,000 people died immediately as a

consequence of the tsunami in north of the Fukushima area. The tsunami or this wave caused the flooding of the reactor building. After the earthquake the reactor were shut down. However, when the backup diesels were flooded and they stopped working, and so, there was no longer cooling of the reactor. External power was not available because it was damage of the infrastructure and this caused the heating up of the reactor core. And so the release of radionuclides started. This is the air concentration close to the Fukushima nuclear power stations and cesium 11 March, the activity per cubic meter at the beginning high releases and they go on for some time. This is the gamma dose rate at the Fukushima nuclear power plant.

The dose rates are 100 mSv per hour up to 10,000 so. It was a severe [ph] release. If you look at gamma dose rates, the highest gamma dose rate outside 20 km was about 170 µSv per hour on 17th of March on this place. These are gamma dose rate at different places around different places of Japan. Okay. So, which protective actions were taken for the public? First of all, evacuation this means the rapid and temporary removal of people from an area to avoid or reduce short term radiation exposure. Sheltering this is a short term use of buildings for protections this means people are recommended to stay indoors, not to leave the house in your location. So, this is non-urgent removal of people to avoid long term doses. And evacuation started very quick. On 11th of March, the earthquake was in the afternoon (0:20:00).

At the evening nuclear emergency was declared and 9 o'clock in the evening, an instruction was given for evacuation within a distance of over 2 km and an hour later, evacuation was in two to three kilometers and stay indoors within 3 to 10 km. And this continued, so the 20 km zone was evacuated and the recommendation was given to stay indoors within 20 to 30 km. And on 22 April there was also remember recommendation given to leave the area NW outside 20 km. And this looks about like that. This is a continuously increasing area where people were recommended to leave or had to leave. Here this is 20 km zone and down there's also outside this one track which goes outside to the northwest is the area. This on 30th of June and here are this is from yes, so this is evacuated. Here people should be prepared to be evacuated and this is a deliberate evacuation so on. And people could in principle stay here but they are recommended to leave.

So there were also some early actions for the public to reduce internal exposure. The measures taken were intake of stable iodine to block the uptake of radioiodine by the

thyroid. This is very effective measure. Then setting a limit for total cesium in food and in the first year for March 2011 to March 2012, there was a limit of 500 Bq/kg and since April 2012 it is about 100 Bq/kg. Monitoring and campaigns were started in the field and on the market. And people were provided with information on the activity levels in food. And the farmers were recommended to use clean feeds if available. I mean, one must say that all these recommendations were quite effective. I mean and the rapid application of such measures kept the internal exposure to the intake of food really low.

This was I would say a real success. And it was immediately more or less implemented. And people also, of course, they were informed and then they tried to avoid the consumption of products from their garden or from other sources. Okay, this was addressed. What you see here is the average dose to representative person in 2012. This is an estimation which has been done by the IAEA on the basis of data supplied by Japan and this is the area which has been evacuated and these are the other areas for which (0:25:00) further on remediation and decontamination activities have been performed. And you see here the doses in 2012 at least they were not so high. Of course, close to the plant and in fact it's 20 km zone. Those are higher than 10 mSv. But in other areas it's well below less than 10 mSv. Interesting is also that here is an area which is not connected to the other areas Ibaraki and Iwate, this is probably due to the effect of rainfall and we have seen that rainfall effectively washes out radionuclides from the atmosphere.

So, which decontamination and remediation activities were done? First of all, the Government of Japan has implemented reference level for remediation of land and we have seen the reference level is a target but not a strict limit. And 1 mSv per year was selected as a long term goal and long term according to the dose, the model which has been applied 1 mSv per year was equivalent to a dose rate of 0.23 µSv per hour. This mean in the following all areas above 0.23 µSv per hour subject to remediation and decontamination measures. The activity in food was 500 in the first year and 100 in the following years for both cesium, cesium 134 and cesium 137.

In Japan, a lot of tests have been initiated to test remediation measures, for example, for houses removal of deposits from the roof, gutters, and decking, wiping roofs, vacuum sanding, high pressure washing trying to remove activity from surface. In schoolyards, top soil removal, removal of weed grass, pasture grass is always removed the upper part of the surface.

Then you remove also part of the activity. Garden and trees mowing, removal of fallen leaves, removal of topsoil, high pressure washing, paring of fruit. In the farmlands, tillering reversal and this is something like plowing, topsoil removal, soil treatments, this was in particular enhance application of enhanced levels of potassium. Soil hardening this means applying a special compound on the top of the soil to make it crusty [ph] and then try to remove this grass. This is a measure to reduce also the amount of soil that has to be removed to have a success. Yes. So, this is what you can in principle do and similar things were also done in after the Chernobyl accident, maybe with different techniques with different equipment, but you cannot in principle do much more than that.

And here are some pictures, removing soil, vacuum cleaning, wiping roofs with the vacuum cleaner, wiping surfaces, (0:30:00) washing houses, removing surfaces. And this looked then like, for example like that, this is before the work and after the work, vegetation was removed as well as here, everything was cleaned. Same as here removing most parts and everything it looks cleaner. However, I mean, this was across some challenge with regard towards the storage of all this material which has been removed from the gardens from the fields from arable land, et cetera.

So in total, about 20 million cubic meters of was generated and about 1000 storage sites and the storage site look like that. This is all flexible containers made from kind of plastic and that was stored in many places around in the Fukushima Prefecture. Meanwhile, activity has started to remove all this plastic bags and they are now put into an interim room storage site, which has been established or constructed close to a nuclear power plant, I think in a distance of three to four kilometers.

And the main components of that is soil, debris and vegetation, branches, all kinds of things. And if you look at the success this is a reduction of dose rate in city of the Fukushima Prefecture. We have here residential areas, farmland, forest close to residential areas and roads. The blue is before the decontamination. The dose rates before decontamination, yellow after decontamination and then the result of post monitoring, post decontamination monitoring is a green one. So, in all cases you see a reduction by a factor of 1.6, 1.5, 1.3 something like that.

There are no miracles but in any case for all these places those rates could be reduced by about 25 to 40%. And it's also important to see that in the residential areas where people live and people stay the effectiveness was highest. Another really big task was the systematic monitoring of locally grown rice. The Fukushima Prefecture has set up a number of facilities which monitor every bag of rice which was produced and should be sold in the Fukushima Prefecture. This was a real little factory here.

And so the rice bags come here, here's a detector, the measurement time is 30 seconds or a minute. And here they are repacked, reconfigured and then everything got labeled and due to the short measurement time measurement had some uncertainty. So the limit is 100 Bq/kg to take account of the uncertainties of the measurement, any bag with a result of higher than 60 Bq/kilogram was sorted out. I mean, if you look at the effect of the overall effectiveness of countermeasures (0:35:00) I mean, the effective measures were to reduce the surface contamination and to reduce the intake of activity, the restriction of food intake and of grazing animals, modification of the agricultural practice, particularly in the Fukushima case, additional potassium fertilizer and also to provide information for people on foods to avoid.

Both from the Chernobyl and Fukushima experience, the dose reduction achieved for external exposure is between 10 and 50%. Following Chernobyl, it is due to these measures 30% of the collective ingestion dose could be avoided, collective means, the doses integrated over all the population. So this is not an individual reduction, but a collective reduction. And Fukushima the ingestion doses could be largely avoided due to strict monitoring of foods and restrictions. And also I think Japanese people are very, very careful.

And so, there were also some measures which we call self-implemented countermeasures just to avoid food which could have enhanced levels of cesium even this is below the limit. Finally, I would like to make a little comparison between Fukushima and Chernobyl regarding the iodine doses, iodine has a half-life of eight days. So it is relevant for the first period only. But I would like to make this comparison because it nicely shows the interaction of thyroid doses due to iodine 131 with living habits and information of the public. First of all, at the time of the accident in Fukushima was before the growing period and in Chernobyl before or during start of the growing period.

I think in Japan in general milk consumption is low whereas in Chernobyl it is one of the most important foodstuffs, in particular the rural population they drink a lot of milk. Also, because there are number of private farmers who have a few cows, those they have access to milk on high amounts. Food monitoring in Fukushima was very intensive from the very beginning. In Chernobyl, it was less intensive in the very beginning. It started slowly. Another point the degree of self-supply, I mean, the fraction of food that people produce by their own, it is low in the Fukushima case, but was high and very high in the Chernobyl case. Then the information of the public was fast whereas in Chernobyl it was delayed and by the end of the day all these factors come up that the thyroid dose due to ingestion was relatively low in Fukushima or nearly very low but was pretty high following Chernobyl.

I mean, we'll have to be aware Chernobyl happened in 1986, this was in pre-internet period, news were distributed very relatively slow and under the political system of the USSR, it was even more slow. And Fukushima we had already the internet it was a more open society. So this information part is essential. But there are (0:40:00) reasons for that I mean, it is as it is and though this causes different level of thyroid exposures. Okay. Let me give again some long term aspects of Cesium in the environment. If you look at the long term process now in the terrestrial environment, we have the radio cesium in soil, we have uptake by plants and to agricultural products. We have also from soil to resuspension, it goes to air and ___ the deposition [ph] plant. And we have this is a kind of a circle resuspension deposition and part of it can be inhaled. So we have water erosion that goes to puddles, ditches and sewers or to rivers, lakes and ponds. Then we come to the next slide which deals with the freshwater environment. For the environment, we have surface run-off. This goes to irrigate irrigation ponds or to rivers and lakes.

And so we have due to surface off a continuous input of radiocesium to water bodies. And then we can have a transfer to crops to external exposure during farming and here consumption of fish or external exposure from sediments. So, sorry, this is not the end, it still continues, but as we will see on very low rates. If you look for the long term behavior of cesium, we have touched this point also in the previous presentation that root uptake, resuspension and erosion and it leads to a continuous to a low but continuous redistribution of radionuclides.

However, the related migration rates are low, for example, the uptake from soil usually is not more than 0.01% per year, which is transferred from the soil to the crop and this has

also be seen. So, this means the removal of cesium with a crop is very low. And this can be compared against the decay rate of cesium 137, which is 2.3% per year. This is by far the most important process for the decline of cesium in soil. The same is with the resuspension.

It is a continuous process, but also less than 0.1% are removed per year. Water erosion is a bit more difficult, because it largely depends on the topography. It is insignificant on a regional scale because it will be removed from one place and it will accumulate downhill on another place. But it could have some local relevance. It may accumulate in some puddles or ditches or gutters this may occur and this may cause locally enhanced dose rates compared to other areas in the sediment. When we look at the countermeasures taken in freshwater systems, there were – first of all to reduce transfer of radiocesium from irrigation water to crops, the measures taken were applied to rivers and lakes, reducing sediment inflow and to facilitate sediment deposition in dams. Dam that is on the water and then nobody is really affected. For irrigation ponds, it was reducing the sediment outflow (0:45:00) and removing contaminated bottom sediments and enhance applications of fertilizer.

However, manipulating sediment is difficult, it is time consuming, it is also costly and sediments will continue to flow into an irrigation pond, for example. The reduction of radiocesium intake by fish in rivers and lake was in particular food restrictions.

No fish consumption anymore at least for a limited period of time, also the application of potassium in lakes. However, it is also difficult. This was also done after the Chernobyl accident. And to reduce external exposure in rivers and lakes, people are stay on the shoreline for fishermen et cetera. This is removing riverbed sediments or have flood controls to avoid distribution of sediments. Irrigation ponds, removal of sediments and covering excavated sediments. I mean, everything the activity [ph] concentration in sediments is pretty high. It can be very high. So a lot of the things are linked to handling of sediments. It always reduced local activity concentrations, local dose rate but the overall impact to the dose to people is very little.

So now here's something I will show some slides where I have given the heading The Trend is Your Friend. And this means that we could observe a continuous decline of activities and dose rates of cesium in suspended sediments, air dose rate of cesium suspended in water and as we have seen before the decline is faster sensor than the natural decay only and it is

due to migration in deeper parts of the soil and then the radiation is attenuated by the overlaying soil. We have also a strong fixation of cesium 137 by clay and this causes a reduced uptake of cesium from soil. And what we see is also everything is more or less consistent with global experience. I mean, one example, for some is here, the Fukushima prefecture, with the contaminated areas, see evacuated zone and the other zones. The message of this figure is just I mean, the red and the yellow parts represent the contaminated areas and we see that these red, yellow areas shrink considerably over five years and This process continuous.

This is from 2016, now we have more than three years more and this area becomes smaller and smaller, even if nothing is done. We see also the suspended sediment of cesium in water. Inside this is number 1 and 2 and outside number 6 of the special decontamination area. I don't want to go into much detail, but in all cases, we see that there is a continuous decline of cesium in water. And we can also see here in this period, there was a decontamination measures were introduced and this caused [ph] accelerated decline of this suspended cesium 137 in water.

(0:50:00) Here we have see, natural decay cesium – no, sorry, cesium in suspended matter of rivers of the Fukushima Prefecture also continuous decline in suspended matter. So the Trend is Really the Friend. And that's cesium in seawater taken from this book. Similar, these are different places, off sites, in the waters around Japan. And also there's a rapid decline and then it continues to decrease. This is cesium in seawater and fish. Here you see this is a fish, zooplankton, sand lance of the crosses [ph], and the seawater is this part.

But from this figure it seems that the decline in seawater is faster than the decline in fish. But in any case, it continues to decrease. And here is the decline of air dose rate decontaminated and control area. This is the decontaminated area and this is the control area. And both I mean, you see the effect of the decontamination and in both post cases the decline continues also in this period for both the decontaminated and for the control area. Okay, that's all.