Gerhard Proehl:

Okay, good afternoon ladies and gentlemen. Thank you very much for coming. Today, I will talk about some methodology for assessment of exposures to people following nuclear accidents. This is a wide field and in this one and half hours which are ahead of us, I can touch any of the fields, but I will give you some flavor. First of all, let's look to the radionuclides, which were in particular relevant following the Chernobyl and the Fukushima accident. These are in principle five nuclides. It is Iodine 131, half life of eight days, very short lived. Then two cesium isotopes, it is half lives of 2.1 and 30 years and they were the main contributor in to the dose in Fukushima and Chernobyl. Strontium played a very minor role in Fukushima. And in Chernobyl there was some relevant strontium release, but the position was more close to the nuclear facility and then Xenon which is a noble gas, where large amounts have been released. Additional, radionuclides have been released. A whole list of them but these are the most important one from the radiological point of view. When we look and we come from the release to the deposition, what you see here is cesium 137 level in the vicinity of Chernobyl and the same the scale the deposition of cesium 137 from Fukushima. So what you can see is that level, the maximum levels are about comparable. But the area affected in Chernobyl is much larger than in Fukushima. Okay, you want to come from the release to the dose.

Let's assume the source is here in an accident we thought we didn't have such a nice deck. Radionuclides are released and people are exposed through main four exposure pathways. First of all, we have the external exposure from the atmosphere. When the plume is passing, people who witness this plume are exposed from radionuclides present in there. During the passage of the plume, radionuclides will be deposited to the ground, either by dry deposition or with rainfall. And people who are on this area will be exposed by external exposure. There is exposure from the cloud is a short term exposure pathway. It is finished once a cloud has passed away whereas the exposure from radionuclides on the ground is a long term pathway. And we have the internal exposure by inhalation during the passage of the plume again the short term pathway and also ingestion of food which has grown on soil which has been affected by the releases. And this is also long term pathway. This is the same a bit more stylized. This is radioecological model. We have here the radionuclides released to the atmosphere, we have activity in air, in rain, deposition on plants and on soil. Direct ingestion of plants or plants are used to feed animals and then ingestion of animal products.

(0:05:00) Uptake of radionuclides by plants from soil and you have the external exposure from the soil and external exposure from the cloud. So how to calculate the doses via these pathways? Let's start with the easy one which is the dose from radionuclides in the passing radioactive plume. So those are mSv, it is quite simple. It's the activity in air x the time exposed x dose coefficient x shielding factor. The dose coefficient is made for free air without shielding. And if you are in a building, you can introduce shielding factor which quantifies the attenuation of the radiation due to the structure of the building so concrete or the roads, etc. The activity on the ground is the same where we have the activity on the ground in Bq/m2, the time, dose coefficients and shielding factor. For radiation dose from inhalation during the passage of the plume we have dose and time integrated activity in air in Bq x days/m3, the breathing rate and the dose coefficient; pretty simple. And the dose in food is activity in food x food intake x dose coefficient. However, the assessment of dose through ingestion food is rather complex because first of all we have a pronounced time dependence.

Activity within food is changing with time. And first one can measure the activity concentration in food by monitoring. But monitoring is always limited in time and space. And it can also be predicted by means of a radioecological model. Let me make one remark to dose coefficients. The dose coefficients convert an activity into a dose. Here we have the energy emission from the decaying radionuclides. This is an energy transport through the air or through soil or within the human body if it's has been incorporated and then the energy absorption which quantifies the dose. And these dose coefficients have been calculated by the ICRP and they are published in many publications in 56, 72 and so on. They are usually done for six age groups; three months, one year, five years, 10 years, 15 years and adults. And the values are given for effective dose and the effective dose is a weighted mean of doses of all tissues and organs. And I will not go into detail how the effective dose is calculated, this is a presentation on its own. However, we have for all these four exposure pathways, we have these dose coefficients to convert activity per unit air volume into a dose rate or activity per unit area to a dose rate or the activity per unit inhales incorporated by inhalation to a dose or the activity per unit activity ingested to dose.

Okay. One short remark by biokinetic model which is used for example for the activity in food, we have the ingestion. This is close to the upper gastrointestinal tract which is resorption by blood and distribution (0:10:00) in organs and tissues or if it must resorbed by the blood it goes to the lower GI tract and finally, it is excreted. And these models calculate the number of the case which occur in the body into different organs and based on this the dose is quantified. Okay. Let's go back to our radionuclides which are relevant. This is Iodine 131. It is a beta emitter with the gamma line. The particular feature of Iodine 131 is it is rapid and very effective uptake by the thyroid after ingestion and inhalation. In our body, we have also stable iodine and the ratio of concentrations from the iodine in the thyroid to the concentration in the rest of the body is about effect of 10,000. So it's an enormous accumulation. So this leads to potentially high thyroid doses and important pathways of fresh vegetables and milk. Cesium 137, cesium 134 are the same elements that have the same behavior. They are only different in the half life and the decay energies are different. However, once incorporated they are relatively homogenously distributed in the whole body and they have also an analogue it is kalium element. So, they have a similar behavior as potassium. This means once deposited on the leaf of plants, they are effectively taken up and there's a strong sorption on clay particles and because the sorptions are strong, very slow migration in soil and in general the uptake from soil is low. However, there is a high bioavailability in forests.

And important food stuffs are meat, milk and forest products. Strontium 90 is a beta emitter. It accumulates in bone. The behavior is similar to calcium and the uptake from soil is higher compared to cesium. The last one Xenon 133, it is a beta emitter with the gamma lines. It is noble gas so it hasn't any reaction with other elements of the ecosystem. And inhalation and ingestion is negligible but there's little gamma. There is some relevance for the external exposure from the cloud.

So here I have summarized the important pathways of these nuclides. This ingestion is always important and external from the ground. External from the cloud is only important for Xenon 133. Okay, after this introduction, I want to go into more detail on the activity of foodstuffs as function of time after an accident. So, the question is which factors are determining the activity in foods? First of all, when you look for the radiological points, we have of course, the radionuclides deposited and the deposition per unit area and whether or not it is deposited as dry deposition or with rain. This is particularly important for depositions which occur during the vegetation period (0:15:00). It is less relevant or not relevant to differentiation if the deposition occurs in winter. And for environmental conditions, of course, it's important about the ability of soils to sorb or to fix cesium or other radionuclides.

The agricultural practice for example use of fertilizer and also the season of deposition, which goes hand in hand with this factor as it is dry deposition or deposition with rain. Season of deposition determines whether we have only deposition of soil or deposition of soil and to plant. So we have relevant food products, of course, this always depends on the area or the region where you are which you consider. And so this may change from country to country and also from continent to continent. However, in any country mostly you have some cereals, in Japan you have rice, in Europe or in United States you have more wheat and such kind of things, tubers and we have vegetables and fruit. Feedstuffs is often pasture grass, cereals but also soy or whatever. Animal food products is milk, beef, pork, chicken, eggs. And then we have also processed food because milk is transformed to butter and cheese is made from milk. Flour is made from cereals and so on. So, we have a number of model processes and parameters. When we look for the first year when we have deposition on the leaves. So, we have the dry deposition to soil and vegetation then the interception of vegetables radionuclides by vegetation. The weathering loss from vegetation and transport of radionuclides in plants to the edible parts. And in the following years or when we have the deposition falling on the soil, we have seen the uptake of radionuclides by plants, migration and fixation of radionuclides in soil, intake of radionuclides by domestic animals, transfer of radionuclides to meat, milk and eggs and then the modification of activity in foods during processing and culinary preparation.

So, I will now go through that. Here again similar message, but a different presentation. So, this should be a tomato plant and here we have this four main contamination routes causing a contamination of the edible part. So, first we have the deposition onto edible part, the deposition on the leaves, then deposition on the soil and uptake and finally four the resuspension of dust and re-deposition on leaves and fruits. Let's look for the dry deposition on the plant. Dry deposition describes the phenomenon when radionuclides are removed from the atmosphere without involving precipitation. That's why it's dry. The dry deposition depends on the plants development. This is often quantified by the leaf area index and this is the area of leaves per square meter of soil and by chemical and physical form of the radionuclide. For example, we have the particle size, in general the dry deposition decreases with (0:20:00) increasing particle size. This is a consequence of the gravitation. Then we have reactive gases as elemental iodine or sulfur dioxide. These are gases which react directly with the plant surface or which have the ability to reach the interior of a plant by diffusion.

And also then we have the metrological conditions. Deposition on wet surfaces is more effective than on dry surfaces. And wet surfaces even on the dry conditions you may have wet surfaces, for example, in the morning as a result of dew. Interception describes the phenomenon when radionuclides in rainwater do not reach soil but instead are intercepted by the leaves, branches of the plants. And again, the interception is also higher if development of the plant has more progressed. So it cannot be also linked to the leaf area index. Then there is a dependence on the radionuclides and then its chemical form and the amount of precipitation. So the dry deposition is quantified by the deposition velocity and this is simply the activity deposited on the ground divided by the time integrated activity in air. And these deposition velocities have been determined through specific experiments undertaking in wind tunnels or in the field. And just to give you some ideas, the deposition velocity of particles is 0.01 mm.

… if per second. Of larger particles, it's about affected than higher and it’s for reactive gases and inert gases these are such gases which do not undergo a reaction with a plant surface at very low deposition velocities. Okay, if you look for the interception of wet deposited radionuclides by plant this is as I said a very important process for the contamination of plant because one thing is rainfall very effectively removes radionuclides from the atmosphere this is one thing. So this means rainfall during the passage of radioactive plume will increase the total deposition to the ground.

And the other point is radioactivity. So, it has been deposited on the leaves will be effectively taken up by the plant and will also be distributed in the plant. The extent of distribution depends on the element. I come to this later. But when we look here at the dependence of interception fraction on the amount of rainfall so, this is interception fraction. This is the fraction of the radionuclides which is retained on the plant and the rainfall. So, you see there's a decline and when it's as high as a rainfall. So, lower this is interception fraction. I mean, this is quite logical and I think you can observe it during any rain. In the beginning of the rain the plant is able to retain most of the rain. But if it's too much rain, you have then this rainfall. The other dependency is we have the dependence with leaf area index and these are experiments made in the United States by Hoffman.

Here again we have the interception factor and the leaf area index and we see a nice increase from the interception faction [ph] with the leaf area index. This is also something we would expect because the largest interface between air and plant the higher this factor should be. And here we have a dependency of the interception of the chemical form. Again, these are experiments from Hofmann. And you see here there is cationic elements onto the yellow and the anions. Sulfur 35 and Iodine 131 and you see there's a difference of a factor of two to four. The reason for this the plant surface is negatively charged.

And so see a retention of the positively charged cations is more effective. In the model, we have to take account of these dependencies. And what you see here is the change of or the development of wheat during the growing period. It starts small, increases, increases and then goes down again. So there's a continuous change in morphology. And here we have both, we have first of all, again, this is wheat, the leaf area index it increases and then it reaches a peak well before maturity well before harvest and then during the maturing period (0:05:00) you can observe that plants get yellow and die off and the leaf area index decreases, but biomass still increases. And in the model we have simplified that and this is – I like that. Slow development, the first part, rapid development, spring and then decline until harvest.

So, when we put analysis into a model and to have the rainfall and interception. So it's a fraction of the activity retained by the crops decreases with the amount of rainfall and it increases with the development of crops and it is highest during the peak season. And you can see here in this diagram can you see it hopefully, we have the rainfall and you have the interception fraction and these colorful lines represent specific leaf area index starting from one to seven. So, we can see more developed the plant is the higher is the interception fraction and everything goes down with increasing rainfall.

The translocation, in this case, translocation describes the active transport of an element in plants and it defines the amount of activity which is transported from leaves to the edible part of the deposition. And it depends on the element. There are two kind of elements. There are mobile elements which are transported in the xylem and phloem. Xylem and phloem are explained in this little picture. In the xylem we have the transport in particular of water from the soil through the stem to the leaves and then we have the evapotranspiration.

And any radionuclide or any element can more or less be transported in the xylem. Then, we have the phloem. The phloem starts from the leaves and it enables also a transport downwards, for example, to the tubers to the roots and in the xylem and the phloem only a few elements can be transported due to some physiological reasons. Then we have this transport from the leaves to the tubers for example is most active during the peak season when the plants have photosynthesis and they but use carbohydrates in the leaves and transport it downwards to the tubers.

So, we have here also pronounced seasonality. And I will come also later, but it is important to be aware of it because this process may exceed the root uptake, which will happen later by orders of magnitude. So, some mobile elements as we said from the phloem to the xylem and examples for mobile elements are for example, cesium and iodine. And for the immobile elements they are only transported from soil (0:10:00) upwards.

This is for examples strontium, barium, radium, the Earth alkali elements and the point is, that is why it is important. Given the case you would have at the position of strontium among the leaves, it would not show up in the tubers because strontium cannot be transported in the phloem. But cesium very well shows up in the tubers after the position on the leaves. And if you look for a translocation factors for wheat, this is to quantify the translocation in a model and these are experiments which I've [ph] done after the Chernobyl accident for wheat and here you see translocation factor.

Function of the time before harvest, again here it is peak about 40 to 50 days before harvest then this translocation is most effective. It starts very low levels and it declines towards harvest because the physiological activity declines as well.

Okay, here's also given the definition of the translocation factor. This is a total activity in grain Bq/m2 per total activity deposited on the plant. And to calculate that is the activity in the edible part of the plant is dry deposition plus wet deposition x the interception factor. This is what is on the plant x translocation factor divided by the yield. I will not [ph] go into further detail with that. But if you apply that, this is an example, to calculate the foliar uptake of cesium by wheat following wet or dry deposition. Both cases we have dry deposition of 1000 Bq/m2 of cesium and translocation factor of 0.1. Let's assume this is four to six weeks before harvest. Then the activity concentration wet as deposition x the translocation factor divided by the yield and this we would come up with 200 Bq/kg approximately.

This is just a rough idea. If you have dry deposition, though we have seen that there's a dependence on the amount of rainfall and let's assume we have dry deposition although it is 1000 Bq/m2 and rainfall of 10 mm. This would come up with a interception factor of 0.5 and if you do the same then we come up with 20 Bq/kg. So, this means because only a small fraction of the trend of the radionuclides deposited remains on the leaves the resulting exposure and resulting activity concentration in wheat is much less. But this differs also on the rain but it's just an idea to give you an idea on the order of magnitude of such processes.

Okay, we have weathering. We have the loss of radionuclides from plants due to weathering. And this loss is due to rainfall or to fog and mist, but also due to foliar abrasion. I mean there's a loss of leaves during the growth and it also includes a decrease of activity concentration due to the increase of biomass. I mean, plants are growing biomass increases so there is a kind of dilution effect. (0:15:00) Important factors are the time after deposition. I mean, the loss rate declines with time after deposition, the age of the plants. For young plants, this is more effective and also by the amount of rainfall and the order of magnitude value it is about 14 days. This means once deposited on the plant every 14 days the concentration decreases by 50%. An example is given here from Fukushima. This is where measurements were done of cesium 137 and iodine 131 activity in weed at 36 km NW from the Fukushima Daiichi nuclear power plant and from measurements were done on 20 of March to 1st of June and during this period the gamma dose rates dropped from 26 μSv/h to 6.5 μSv/h. Not due to the decay of cesium but it was due to the decay of iodine and also radionuclides, which I had not mentioned before, because they are so short lived.

You see here this rapid decline and the decline of iodine is fastest in cesium due to the shorter half-life. And at the end of this period, there's obviously no further decline and this is about the level due to the uptake of cesium from the roots. This is just a compilation of weathering half-lives for selected elements and for some plant types. This is taken from this book published by the IAEA. It is the handbook of parameter values for the prediction of radionuclides transfer in terrestrial and freshwater environments. And this is a compilation of many important radioecological factors.

Radionuclide uptake from soil, this is a potential long term source of contamination of plants and foodstuffs. First of all, it depends on the soil characteristics and sorption capacity, sand, loam, clay content, organic matter content, the pH value, for some radionuclides it is redox potential in particular of iodine and plutonium and also for the concentration of antagonists. As we have said before, the antagonist of cesium is potassium and of strontium is calcium. But also on the use of fertilizer because we use also potassium fertilizer in this way has an effect on the uptake of cesium as well.

The depth of root is a factor. The chemical form of the deposit, I mean, radionuclides are released in different chemical forms. Some are inert particles other are more soluble. So this has to be taken into account and of course, also the time since the contamination of the plant. And as time goes by in particular, cesium is very well sorbed and fixed by the soil. The transfer factor or the uptake of radionuclides from the soil is quantified by the transfer factor.

This is a concentration ratio of the activity in plants by the activity in soil, very simple and the transfer factor have been measured since more than 60 [ph] years now. And there's a quite an enormous database available, at least for cesium. In some cases, another definition is used. This is the (0:20:00) activity concentration in plant and the deposition to soil in Bq/kg fresh activity concentration in soil per activity per Bq/m2.

So this gives a fraction which part of the deposit is in the soil per square meter. And this is in particular used on areas where it's very difficult to measure the activity concentration in the soil because there are very pronounced gradients. It may be high in the top and very low in 20 centimeters. That's why one uses the total deposition. Here are some numbers. Some typical values for the transfer factor I mean for the concentration ratio.

Again, this is in this handbook. Meanwhile, after the Fukushima accident, also more data appeared for strontium, it is about 0.1 to 1, cesium it varies depending on the type of soil. I don't want to go into further detail. This is just an idea. But you also see that, for example, elements like plutonium or americium are very well fixed in the soil and the uptake by the plant is very low. Some remarks to cesium in soil because it is a bit special. If you look for intensive farming, usually you can observe the strong fixation of cesium to the clay particles. That means it has a low uptake from soil and also slow migration in soil. And due to the antagonism with potassium, the uptake of cesium declines with increasing potassium levels. However, there are some special cases for cesium in particular in the farming in natural and semi-natural environments. Because then we have a potential high uptake from soil if the clay content is low, if the pH is low, if the…

Potassium supply is also low and then we find persistently high levels of cesium in mushrooms and berries, in game and sheep. And we could observe such phenomenon in the Highland areas U.K., in Northwest U.K., but also many of regions with organic soils in Russia, Belarus, Ukraine and Scandinavia. Then the uptake of cesium is by about a factor of hundred higher than for intensive farming. In Japan, as far as I know, this phenomenon doesn't play a role. It may occur here and there I don't know. But I have never seen data which would really supports this.

So, let's look again for the estimation of root uptake. This can be covered by the activity in soil, the deposition, the ploughing depth or the mass of soil per of the upper layer. And so if you have a deposition of 10,000 Bq/m2, we have something like 30 Bq/kg soil in the upper layer and if you apply a transfer factor of 0.1 for cesium become up with an activity concentration in plants of 0.3 Bq/kg or deposition of 10,000 Bq/m2. So, this means less than 0.1% is comes up in the plant. So by and large the uptake of cesium by the root is relatively low. And if we come back to our estimation where we have estimated the resulting contamination of cesium from foliar uptake we come up with this comparison.

Again, we have the root uptake and foliar uptake and for dry deposition and for wet deposition. For root uptake, it doesn't matter whether it's dry or wet deposited, sooner or later it comes to the soil. But for foliar uptake the difference is quite, quite high. There's are some differences between dry deposition and wet deposition, but you see also difference between foliar uptake and root uptake, assuming a foliar uptake during the peak season of the plant and then you see that.

Then you must say or we have to say so, far we have been very lucky with the nuclear accidents because they all occurred at the beginning of the growing period when plants were not affected or affected only to a very small extent. So, we have not seen a direct contamination following a direct deposition on plants during the peak season. And this was a case in Chernobyl as well as in Fukushima.

The resuspension of soil, this is a pathway which is in principle of minor importance and it describes the phenomenon that due to the action of wind. Small soil particles contaminated soil particles come from the soil to the lower atmosphere and this depends on the kind of soil, the soil texture and the humidity, the vegetation cover and the wind speed. And I mean, (0:05:00) this is particularly important for dry areas, for arid areas, desserts, semi deserts or in summer when soil has dried out. In temperate climates, resuspension during storm may cause a relevant activity loss from soil.

The other point is the resuspension should be taken bunch of ___ to have in mind because since this is not a continuous process, it largely depends on the wind speed and it's only active when the wind speed is above a certain threshold. Then it may really come relevant. If wind speed is low or zero or close to zero, we will have no resuspension. So, by the end of the day the resulting contamination of the plant is low and you can see only a relevant contribution to the root uptake. If the root uptake is low then resuspension may contribute and root uptake is low, for example, for transuranic elements like plutonium, americium then this may be relevant, but it will always be on a relatively low level.

Factors which cause higher resuspension is I mean, a low coverage of the soil, depends on the particle size and one thing is also important radionuclides may be enriched in this fraction which is resuspendable. And this resuspendable fraction and the enrichment in this resuspended fraction can be as high as a factor of 3. The model is usually quantified as kilogram soil per kilogram plant. And for temperate climates due to resuspension, we have about 0.01 to 1 g soil per kg plant.

Okay, transfer to animal products. This depends on and this is due to the use of contaminated feedstuffs. And then we have a transfer to milk, meat and eggs and for this we have a very simple model. We have the activity intake and metabolic model what happens with the radionuclides in the animals and then we come up with the activity in meat, milk and eggs.

Of course, the animals have to eat something and here we have to the dry matter intake of number of animal species. These are rough values. Feed intake is very variable. It depends on the size of the animal, the performance and many feedstuffs are the type of feedstuff always depends on the availability and usually animals eat such things which are not eaten by humans. So dry matter intake depends on milk yield, on the age, on the growth et cetera. And we have here also a simple model. We have time and assume we have an activity a constant activity intake with time. This is over this period. Then what usually can observe is first day an increase until a certain level when we have reached the equilibrium. And once at that time we stop activity intake, then the activity concentration declines. So, this means this is defined by this level and this is called the transfer factor. (0:10:00) I will come to this in a minute. And by this biological half-life which controls the excretion from the animal. The transfer factor is for feed meat and eggs is defined as a activity in meat, milk and eggs Bq/kg divided by daily activity intake Bq/day.

So, the unit is then Bq/kg divided by Bq/day/kg. Again, it depends on the element, the chemical form, and feeding diets. So, a lot of data about that, in particular for cesium, strontium and iodine, but not so much data for other elements and we have also some data to describe the biological half-life. Again, this is some typical values for the animal for the transfer factors. For example, for cesium we have 0.03 this means in one liter of milk, we have 0.3% of the activity, which the animal has taken per day. This means if a cow takes in 1000 Bq/day, we will have 3 Bq in the milk on the equilibrium and so on.

And the next parameter is the biological half-life. For cesium, iodine, strontium and for milk, the biological half-life is relatively short. It is about 1.5. For milk, we have two components. Rapid one and slower one, but the rapid one is more important. And for beef and pork, we have half-lives of about 20 to 50 days. This means once equilibrium has been reached in milk or meat and you stop feeding cesium then you will have the decline will follow the half-life of 20 to 50 days depending on the radionuclides. Example is shown here. This is an example of the cesium in milk following the Chernobyl fallout in spring 1986.

This is published by UNSCEAR and the data are from dairy farm near Munich. And every little dot here is one measurement of milk. It happened in spring and the beginning the activity in grass was highest and then it dropped due to weathering and due to growth dilution until summer and autumn. However, then we have in autumn an increase because in winter the hay ___ feed which has been produced in spring and early summer. So, during winter we have a kind of a plateau or close to plateau and then the next spring a decline again coming down about to the level of foodstuffs.

And here you see the dots and here you see some model, this dotted line and the mean value of the line. So food processing and culinary preparation. I mean often we eat the crops directly as for example, leafy vegetables, fruit, vegetables or fruit. (0:15:00) They are washed but nothing more for but we have also products which will be processed, for example, from cereals to bread by a flour or from milk to butter. And this can be quantified by a processing factor which is the activity in the processed food divided by the activity in the raw product. This is a number of processing factors for cereals, vegetables and milk.

Just to show you some examples, I mean for wheat if you make flour from wheat, then you have less activity concentration in the flour. It's 50% lower, but the rest is in the bran in the outer parts of the grain.

If you make butter from milk the activity concentration decreases by 80%. For cheese, it's a bit different, what kind of cheese you have. For strontium, you may have an enrichment of strontium in the cheese sorry. So this is just few examples to make you aware of this process and something which is important for Japan. There is processing of rice, for example, if you have brown rice and the milling to white rice, you have also a reduction in the white rice by 50% or by washing there's also removal of 40%.

And when you have the brown rice, boiling rice after milling to white rice and washing the activity concentration comes down by a factor of 8 approximately. All this again, many of these factors are compiled in this report. The time dependence, I mean, if you look at all these factors foliar uptake, food uptake, weathering et cetera., this can be simulated in a model for instance this is a RODOS model. This is a model which is widely applied in Europe for accident consequences ___ management.

And this is the example of Chernobyl fallout in Germany. For example, for leaf and vegetables we have a rapid increase and internal rapid decrease, because since the growing period of leafy and vegetables is very short because we eat it very freshly. And then of them we have come up to a level which is given by the root uptake or for milk we have shown this figure before rapid increase in spring, decrease onto summer, increase again during the winter feeding and for potatoes in this case they were not affected.

Okay. So we are able to simulate to calculate the activity concentration in foodstuffs after deposition to the soil. And then we come with an intake of radionuclides with foodstuffs. This is a bit tricky. I mean, the activity intake is the sum of all intakes via the different foodstuffs and the consumption rates of the foodstuffs. So this is the activity concentrations of the foodstuffs, consumption rate of the foodstuffs. (0:20:00) We have an idea about activity intake, ___ about the activity concentrations of the food. But the problem is always the food intake because the food intake is very variable. And we have eight billion people on Earth and we have maybe eight billion different feeding habits, consumption habits, sorry. First of all, where we have national habits, regional habits, individual habits. It depends on age, gender, people living in cities, many other things and people living in rural areas, after an accident, after contamination.

There are anxieties which cause people to avoid specific products, such as reaction and there's also a reaction of the food processing companies, because they may stop the marketing of some foodstuffs from certain areas. I mean, this is all things we have seen after Chernobyl and after Fukushima. There are food restrictions and limitation and also information on food contamination which may cause the people to change their consumption habits. So, this is difficult and it depends from case by case. This is the default food consumption by IAEA for different continents, which more or less, reflect what people eat. For the Far East, marine fish and freshwater fish is important, in North America, a lot of meat, such kind of things. These are all average values and do not necessarily represent the values for individuals. Same in the RODOS, there's also some default intake rates. I don't want to go into detail.

Just want to show that this is a variable parameter which is difficult to estimate in particular in an emergency situation. However, having said that, and going one step further from the activity, we had its function of time in different foodstuffs. We have now predicted doses via different exposure pathways following the Chernobyl deposition in Southern Bavaria. This is an example. I mean, I could also have another example but we have here wet deposition for cesium at 16 kBq/m2 [ph] at 5 mm rain and an activity in air of 300 Bq h/m2. This is exposure from radioactivity on the ground, the cloud, inhalation, ingestion and total. You see in this case exposure from the cloud and inhalation is not relevant and so the relevant pathways are exposure from the ground and ingestion. What we also can see is ingestion starts relatively quickly. This is total dose after one day at one week, two weeks et cetera.

So after the first year, first two years there is hardly any increase whereas for the ground, it's different. It starts slowly and over 70 years, it comes up to a total accumulated dose which is comparable to the ingestion dose. What we have done here is we have tested this model and we have made measurements of cesium 137 in the whole body counting of the near Munich so forgive me. And we have different groups that are males, females maximum, minimum.

The red curve is the prediction of the model and the other are represent specific population groups. What we can see here is in the first year the model overtakes by about a factor of 2 the intake which is not so bad. And this all prediction comes due to the origin of food. I mean Munich was an area which was more affected than other areas. So, many foods came from outside which caused then a reduction of intake. On the long term, it looks quite reasonable.

So, what you can see here is I mean this is a good example. There are also other examples which look not so good if you compare models with measurements. So, but it's a good example. But it also gives us the question how can we on the long term improve the models and how it can be improved the confidence in the models. And the first step and this is a careful model analysis. We have to compare the assumptions of models and the revisions assumed (0:05:00) with say situation for which the assessment is done. We have to identify sensitive assumptions and parameters and give more efforts to identify appropriate representation of such processes. Another thing is in order to perform a systematic uncertainty analysis and to explore uncertainties and variabilities and to identify important parameters.

And of course, the characterization of the site is a key issue to have the agricultural practice right, to have the growth right or the lifestyle. And finally, improve results of a model is also by comparing with data from monitoring of radionuclides. I mean, whenever there's a nuclear accident or the contamination, we will not have only models but we have also monitoring. And it's important to compare this with monitoring data for activity in food, feed and soil and also time series are very helpful. We have seen one example that in-vivo measurements for the whole body and the thyroid are quite useful to see where we are with the model predictions or after I think Japan and those of in Chernobyl individual dosimeters reduced to estimate external exposures.

So by the end of the day, monitoring and models go hand in hand. Model, we provide measured results, they allow us to check and calibrate the models. So question is always how representative is really a measurement in the field? Has measurement been done on the right place at the right time? So does it always tell the truth and here comes the model again into play, where models help to understand measurements, to interpolate in time and space and also to extrapolate to the future and to fill missing data. So, and I have only a few words at the end.

We have seen that doses due to environmental contamination are the result of a really complex interaction of deposition, agriculture and environmental conditions, the lifestyle and economy and food supply of the people. When we look at the plant uptake of radionuclides following deposition we have seen that foliar uptake can be much more effective than uptake through the roots. But, foliar uptake is subject to a pronounced seasonal variations in the plant's development stage. And foliar uptake is only relevant for depositions during the vegetation periods. And at the end we have seen that the combination of results of models and monitoring may improve the model reliability. Thank you very much so far.