Gerhard Proehl:

Now I will give you an overview of the options of disposal of radioactive waste. Before we go into detail, let's talk a little bit about the disposal terminology. Disposal means emplacement of waste in an appropriate facility without the intention of retrieval. This means the waste should stay at the disposal site forever. And this disposal facility, this is an engineered facility where waste is emplaced for disposal of course. There are near-surface disposal facilities which are located on the earth's surface or within a few tens of meter below the ground level, so everything is very shallow. In contrast to that there are geological disposal facilities, these are facilities for radioactive waste disposal located underground and usually several hundred meters or more below the surface. A stable geological formation is needed to provide this potential for long term isolation of radionuclides from the biosphere.

The aims of disposal of radioactive waste is quite simple, is to contain the waste, to isolate the waste from the accessible biosphere, and also to reduce the likelihood of inadvertent human intrusion into the waste. I mean the knowledge about this disposal might get lost and future generations might look for some mining activities, might look for some commodities, and may unintentionally intrude the disposal and this should also be avoided due to design features.

So, we look at the current status of disposal of waste. I mean several designs have already been developed for the disposal facilities and these designs have a different degree of containment and isolation capacity and this depends on the type of waste and the activity which should be disposed off. I mean in some countries various types of disposal facilities have been constructed and are all in operation.

Let's look at the waste classification scheme. A number of classes, dependent on the half-life and also on the activity in the waste. First of all, this is high level waste and high level waste is mainly some spent fuel or waste from reprocessing. We have intermediate level waste and low level waste and very low level waste and very short-lived level waste. This is so to say categorization depends on the activities which are present in the waste or on the half-life. Sometimes it is also about exempted waste, this is waste which is radioactive, but which cannot be managed. For example, this could be waste containing potassium-40 from fertilizers, something like that. And here we have again this very short-lived waste, very low level waste, low level waste, intermediate level waste, high level waste, and depending on the activity and half-life, I mean lower the activity or higher the activity, greater should be

the depths at which the waste should be disposed off. (0:05:00). So, high level waste goes to the deep underground, so geological disposal, whereas very low level waste and low level waste can stay on the surface, of course with some technical barriers.

This is an example of near-surface disposal, this is for short-lived radioactive waste or for lower active resources, and this can be found in some countries. Geological disposal is not available yet, but geological disposal is going to be – licensing procedures are going on in Finland and Sweden to construct and operate such a geological disposal facility for high-level waste. An idea which came up during the last years or 1 or 2 decades is the borehole disposal. This could be appropriate in particular for countries which don't have big nuclear programs, but which have only some sources for medicine or for research, because this borehole is suitable for all types of disused radioactive sources and it provides a safe and secure solution and one has not to wait for until a geological disposal is finished or is in operation. However, borehole disposal is also not available yet, it's still an idea. So, all of this, we have this disposal system consisting of confinement where the waste is disposed off in the geosphere with overlying rock and the biosphere.

And if you go again for the terminology, ___ containment, these are methods or physical structures to prevent or control the releases and the dispersion of radioactive substances. The confinement is prevention or control of releases of radioactive material to the environment in operation or in accidents. So, the most important point for disposal is the isolation and the isolation capability and isolation means this is a physical separation and retention of radioactive waste away from people and the environment and this may need to look at timeframes of several hundred years for short-lived waste, I mean short-lived also in this context is also ___ so several hundred years would be 10 or more than 10 half-life ___. However, the intermediate level waste and high level waste has to be looked at more carefully and the period is for at least several 1000 years. The isolation, of course, this is an inherent feature of geological disposal. So, the disposal system, what we have the near-field, are types of waste – The origin, the nature, the quantities, and the properties of the waste, and finally, the radionuclide inventory. Then we have some system engineering for waste conditioning and packaging and disposal units and engineered barriers that cover the disposal facility and drainage features. We have also to know about the extent and properties of the zone disturbed by any excavation or construction work. All these features have to be taken into account in the safety assessment. Then we have also the far field. (0:10:00) The far field is the way from the facility to the biosphere and it includes geology,

hydrogeology, hydrology, and geochemistry, and finally the biosphere, the location of disposal facility, climate, and atmosphere, water bodies, the biota, the salts present, the topography, and the area of the site, and of course the local population and human activities.

Let's talk about some examples of planned or existing disposal facilities. Let's start with near-surface facility, which is landfill for very low level wastes. In Lithuania, and this is just a buffer storage facility, and it is located close to the Ignalina Nuclear Power Plant in an industrial site, it's in operation. It's very low level waste. It contains relatively low activities. The waste is stored – is disposed in such disposal modules. We have the waste ___ and here we have some barriers to prevent that waste from entering the biosphere. This is in Ignalina Nuclear Power Plant. This is the same again, Ignalina. Here you see the waste packages. Waste is compacted or packed in such flexible intermediate bulk containers. Again, here is the waste and this is surrounded by barriers to prevent leakage.

This is a near-surface disposal facility in France and it is for very low level waste. You see here some pictures. This is a facility and all waste disposal in this facility is done under this mobile shelter and there are a number of mobile shelters. This facility went into operation in 2003 and it is dedicated for very low level waste and it was the first of its kind in the world. In this facility about 30,000 cubic meters are disposed per year. There are trenches, nearly 180 meters long and 25 meters wide and they are dug several meters deep in a clay layer and after filling, the trenches are covered by a capping system composed of natural materials and a geomembrane, ensuring water tightness. As I said, all operations are conducted under the mobile shelter. So, mobile shelter can be moved from one trench to another on a rail-sliding system and the interesting thing is that disposal cells are excavated directly in a clay layer, down to depths of 8 meters. And the trenches are operated one by one. If one is free, disposed, and then the next one starts. So, in this case only one of the trenches are open, all others are covered. When people work on it, then it is covered by a shelter to prevent (0:15:00) intrusion of rain and water.

Here you see is a profile, the disposal trenches are between 0 and 30 meters underground, above the water table and the trench is dug into the clay and in the post-closure phase everything is filled with material which prevents the intrusion of water.

This is another example of near-surface disposal. These yellow barrels are very famous, they are disposed here in layers and then covered by material, but this is not in France, this is somewhere else.

Here we have the example of a near-surface disposal facility in El Cabril, Spain. It is also for very low level waste, for low level waste and intermediate level waste. Everything is above ground and these are, so to say, the technical barriers for this disposal. Here you see a scheme of this disposal facility. I mean this is very simple. This is just a big concrete structure which is protected against wind and weather.

This is a plant, near-surface disposal facility in Belgium. This is for category A waste. Category A waste is short-lived waste with low and intermediate level specific activity. I mean it is mainly short-lived but may contain also some other stuff. This has a volume of about 50,000 cubic meter and about 0.5% of total activity of all waste. And this looks like that in the operational phase and in the post-closure phase. Then it will be covered by some material. This again is the Belgium example. So, there are 3 types of monoliths which are used for disposal of waste in this structure and this disposal facility has a fixed steel roof attached to modules, an inspection room and an inspection gallery to allow inspection.

Let's come back to borehole disposal activity for radioactive sources in more detail. So, a hole is drilled to the underground to depths of 100 meters or more. Then the waste packages are filled into this hole and then everything is packed with some material, often bentonite which has some absorption effect and we have repository seal and then that's it. It's quite a simple concept, but it is only applicable for sources with a very small volume. Nothing for large volumes. You can see, again, this canister also has some barriers. This is a container of the source, this is the capsule, then we have some pack filling and another barrier. So, there is a number of barriers. This is a multi-barrier system to prevent such materials cannot leak.

This is in Sweden. This facility (0:20:00) was designed for disposal of short-lived radioactive waste, with low and intermediate level activity from nuclear power plants, hospital, industry users and facilities. It is underground. This is Baltic Sea, this is the shoreline, and it was built between 1982 and 1988, at depths of 5 to 100 meter in a structure under the Baltic seafloor, about 1 km away from the Forsmark Nuclear Power Plant. The waste here is deposited in cavities, which were excavated into the rock, to be flexible in configuration that

the waste fits well. This facility is in operation since 20 years. Close to this area the Swedish disposal facility for high level waste is planned to be constructed, and as you see, this is on the shoreline. It is under the seabed and this landscape will change in the next 1000 or 10,000 years, and all these water bodies here, due to the lift of landscape, this water will disappear and the sea will fall shallow. This is a new disposal facility, also in Sweden, in the same area, and this is for intermediate level waste. This is similar in design, it is underground and very old granite and the waste is then stored in such structures. Structures are sealed and at one point in time everything will be closed.

Let's go to geological disposal for high level waste. Again, this is high level waste and this is also in Sweden. The host rock is granite, the granite is very old, I think billions of years, pretty old, and in this granite caverns are excavated and waste is put into such holes. These are copper canisters with height of 5 meters. Copper canisters have a diameter of 1 meter and the mass is about 25 tons. So, it needs huge machinery to handle this stuff. Then they are put into this hole and then sealed. This is copper, copper is used because this is granite, granite is not a dry host rock, because it always has some pores or some cavities, some passes where water might infiltrate and that's why copper has been selected and this should seal the waste for a very long time. In total a huge amount of copper will be disposed off also in this disposal facility. Here you see such a copper canister and this will be fixed, the upper part will be fixed to that. (0:25:00). This copper goes into ___.

Let's start with the spent fuel. There is a container for spent fuel and this spent fuel containment goes into the copper canister. The copper canister is sealed and this is then put into the caverns in the crystalline bedrock at depths of 500 meters. And the canister is surrounded by bentonite clay in individual deposit holes. The total cost of this, at least an estimation, that was communicated to me 2 years ago or 3 years ago, was about 10 to 12 billion Euro, it's about 10 to 12 billion dollars something in this order of magnitude.

This is some geological disposal for high level waste in Finland. It's in principle similar. So, host rock is the same, it's also granite, and again, there is the fuel, the fuel goes into the assembly, into the canister, the canister into the copper, the bedrock, and then filled with bentonite for sealing at depths of 400 to 500 m. This is a disposal for high level in Finland. It is also close to the sea. Finland, very likely, will be the first ever facility for the safe disposal of spent fuel. This is in Finland. You see a cavern in the bedrock, in the granite. So, granite is a very hard rock, so you can imagine the efforts to construct such caverns. This

requires really special equipments. This disposal is called Onkalo, in Finland, and it consists of system of such tunnels. Also this system or these tunnels are used to characterize the host rock, which also provides an important input for the development of the safety case and the safety assessment.

This is from the United States, and this is the so called WIPP, waste isolation pilot plant, and it is authorized to store transuranic radioactive waste for 10,000 years. The waste is from research and production of United States' nuclear weapons. It is quite similar, there are underground caverns and they are stored or disposed off in special containers which prevent – which gives an additional potential for isolation.

This is in Germany, one example. This is a geological disposal of low and intermediate level waste. It started, the planning started I think in 1982, there was the first safety report on this. It is a disposal site in a former iron ore mine near Braunschweig in Germany, this is the one in north. So, the first plans were in 1982 or something like that. Now its schedule is to start in 2022, closure to be a few years later, (0:30:00) I don't know, and the maximum capacity is about 303,000 cubic meter of waste. It is an old iron mine. This mine is very dry, because over the iron mine there is a very thick clay layer which prevents rain water and ground water to go into this disposal facility.

Let's come to the summary. I think we have seen some examples of waste disposal facilities both for low level waste, but also for medium and for high level waste and these concepts which are in construction. So, I think it is important to know that we can learn from other member states' experience and design solutions and to know what works well and what work not so well to have continuous improvement of such disposal systems. We have also seen that there are many ways of providing long term safety and many concepts and obviously there is no single best disposal solution for near-surface or geological waste, everything depends also on the geological circumstances in a country. I mean Swedish disposal facility is on granite, because they have only granite as a host rock. In other countries there might be also salt formation, which are suitable for waste or clay formation which are suitable for waste. So, this depends on country by country. I mean we have different kind of wastes, so we need also different types of facilities to be designed to address the disposal inventory and also to take into account the characteristics of the site and the available resources. Technical and natural barriers need to be explored and evaluated to assess the long term safety and this is the key element for the development of

the safety assessment and the safety case. And as this is quite a long term process to come back to construction and design construction of disposal facilities, it is also kind of a continuous iterative process between design and safety assessment facilities and looking at it in a holistic view, considering the whole system.

Thank you very much.