Joachim Knebel

Chief Science Officer (CSO), Karlsruhe Institute of Technology (KIT), within Helmholtz Association of German Research Centres

Breaking the Wall of High Level Nuclear Waste. How Partitioning & Transmutation can Help to Reduce the Radiotoxicity.

21 years ago I was working for PhD at Karlsruhe University. The news was thrilling, as nobody could have expected such a good and peaceful outcome.

Good afternoon everybody; I am going to talk about the wall of high level nuclear waste. During breakfast this morning, most probably you saw the front page of the German newspapers. There are very emotional pictures of people demonstrating against the transport of high level nuclear waste. There is a kind of wall possibly building between parts within our society, and I think we, from the scientific point of view, have the chance to work on a solution. So the motivation is to deal with the high level nuclear waste, to possibly even kind of get rid of it. (? 1:25:34 *name*) already mentioned that we need the closed nuclear fuel cycle, so technology like with the recycling of coke bottles to take back the waste and to deal with it. I will present technological solutions, which are not at hand today, which could be at hand in 20 years. Then, I propose the few next steps.

You all know, and (? 1:26:02 *name*) expressed this: Today's nuclear power plants are essential for the electricity production worldwide. 16% of the electricity is produced by nuclear power plants, 20% in the European Union, and 25% here in my country in Germany, mainly for base load electricity; so the electricity that all of us use the whole year long- 25 hours a day. It is safe, economic, it doesn't produce CO_2, and it reduces our energy imports. However, you always have to remember these existing nuclear power plants produce high level nuclear waste. This high level nuclear waste is of public concern, and this concern must be answered, must be dealt with, and must be solved, in order to make nuclear sustainable.

One possibility on the way of the waste that comes from the nuclear power plants- on the left hand side- via the castors that are transported right now in Germany to a

possible final repository site. It is the idea of partitioning and transmutation that is, to say, to deal with the waste, to reduce its hazard potential, its harmfulness, that we scientists call radiotoxicity. Here I have plotted the radiotoxicity, the hazard potential over the time, in a double algorithmic scale. So, when the fuel comes out of the reactor here at time zero, it takes several one hundred thousand years till the radiotoxicity, the hazard potential, has decayed to the level of the natural uranium, out of which this fuel is done. This is not satisfactory; this is extremely difficult to provide these final repositories. That is why we extract the plutonium, the uranium, recycle it, burn it, and then we come to something that is like 16,000 years that we have to deal with the left over waste. But if we, in addition, and that is now the new step, also extract, partition the minor actinides: americium, curium, neptunium- these really high level parts of the waste- and recycle it, then we shift from these very long geological time scales to something in the order of a few hundred years of historical time scales.

That is the aim where we want to go to. We want to reduce this radiotoxicity, the heat load, and the volume of the waste that has to be disposed of in a final repository. So, the volume can be reduced by a factor of 100, the radiotoxicity in the order of 1000. So this is really remarkable. Still, we will need a final repository for the losses of the processes for the fuel that we cannot deal with. But anyway, we go in the direction of a closed nuclear fuel cycle.

How does this Partitioning and Transmutation work in a Closed Fuel Cycle?

This was all very theoretical, so I would like to show you what we do today. We have the fuel that goes in the Light Water Reactors (LWR), second-generation reactors or third-generations like the European Pressurised Water Reactor (EPR) being built in Finland and France. We either directly dispose of the waste- this is the maximisation; this is not clever. You should reprocess it, take back the valuable stuff out of the waste: uranium, plutonium- refuel it and burn it.

But, in the second step, and that is what we are proposing from a scientific point of view, you also should take out the minor actinides, put it in a special transmutation machine that burns the waste. As you cannot do it in a once-through mode, you have

to do it several times. So, you have to partition it again; you have to leach it out. And if all this in equilibrium, the existing Light Water Reactors and the transmutation machines in the end, in the optimum case, only the losses have to go to a final repository.

Now what does such a transmutation machine look like?

We have two options. With Light Water Reactors they have thermal neutrons, which cannot deal with the plutonium, with the minor actinides. They cannot destroy them effectively. That is why we need fast reactor systems, and there two options. One: are the Fast Power Reactors of Generation IV that are internationally developed in the Generation IV International Forum. So there we have three possibilities, depending on the coolant utilised. It can be Sodium Fast reactors, Lead Fast Reactors, or Gas Fast Reactors. They are presently being developed. The Sodium Fast Reactor, for example, is being built in China and India; so countries that do expand their nuclear fleet. If we combine these Light Water Reactors with these Fast Reactors, we will succeed to stabilise the radioactive inventory.

However, if we want to reduce it, we need another type of fast system, which is called an Accelerator Driven System- ADS system, which consists of a proton accelerator that shoots the protons on a spallation target here in the core. There the needed high power neutrons are produced that in the subcritical core, where the plutonium and the minor actinides are arranged, make the fission and (? 1:32:04 *caption)* reactions that in the end destroy the minor actinides. So, due to the subcriticality level of the machine, we have improved safety characteristics. If you shut down the accelerator, the fission reaction shuts down. And with this machine we can reduce the highly radioactive inventory of the waste.

What are the open questions?

It is not as simple as I have put it here. Of course, since many years in an international community, we are working on the fundamental research, for example: how can we get out these minor actinides from the waste? We did many steps forward. We know how to do it in a lab scale, but we have to go on an industrial scale. So, this is really a big challenge, and the international colleagues are working

on it. We have to produce the transmutation fuel itself. This is extremely difficult; it has to be remote handled. This will take some time. Where we did excellent progress is in the design of the spallation target. So therefore, for example, in Switzerland we operated one of these spallation targets successfully; so we know that this is operational. One of the open issues is: how do we come to a demonstrator? How can we show that all the fundamental investigations that we did in materials: in thermohydraulics, in neutronics, in fuel manufacturing; how can we combine this to an operational machine to such an Accelerated Driven System to show that this is feasible?

There, of course, I would like to show the world map of all the partners that are contributing to this development since many years. It is, as I said, this International Nuclear Forum that concentrates on the Fast Power Reactors that can stabilize the waste in combination with the Light Water Reactors. It is the European Commission, where there are framework programs that very heavily sponsor this technology in the ADS system. You see that really all the major countries worldwide follow this development. In the EUROTRANS Project, a huge European project, this year we succeeded really to design such a machine. We are sure it would work. It is just the question who would build it. Could we really demonstrate that this is feasible from a scientific point of view, from a technological point of view? Then there is the question: who takes this up, who would build it to introduce it in the closed fuel cycle?

There comes the reason why (? 1:34:50 *name*) was here. In Belgium, in the national nuclear research centre, in Mol, there is the idea to build such a transmutation device as a European, as an international unique experimental reactor, to really see whether transmutation is feasible or not on a large scale. So the full operation of this facility could be in 2023; it is in the order of one billion Euros, so it is a huge enterprise. I think all the countries worldwide should stay together to really show that this is technically feasible.

My summary, my conclusions: I think to make nuclear energy sustainable, today it is not; the Light Water Reactors keep continuing to produce high level waste. To make nuclear energy sustainable, we have to recycle and to close the nuclear fuel cycle. This can be done by the strategy of partitioning and transmutation in a combination of

Light Water Reactors, Fast Reactors, and Transmutation Systems. There is some time to go, but we have to tackle this problem- no matter whether we like nuclear or not. These are the famous stickers on the cars. No matter how a country decides, we have to deal with the waste. Just to finish, of course, it is not the work that I did. I am kind of representing a huge international community where some of major players are mentioned here. It is for their benefit that I was allowed to talk about possible transmutation of high level nuclear waste. Thanks a lot.