Interactions between Sodium and Fission Products in Case of a Severe Accident in a Sodium-cooled Fast Reactor
Mr. Guilhem Kauric, CEA, France

Berta Oates
Doing today's introduction is Dr. Patricia Paviet. Patricia is the technical group manager of the Radiological Materials Group in the Nuclear Sciences Division at the Pacific Northwest National Laboratory. She's also the chair of the Gen IV International Forum Education and Training Task Force. Without any further ado, I'll let Patricia do the introduction.

Patricia Paviet
Thank you so much, Berta. Good morning, everyone. I am very happy to have Mr. Guilhem Kauric giving his talk today on the interactions between the sodium and fission products in case of a severe accident scenario. He's one of the three students who won the Elevator Pitch Challenge contest at the last GIF Symposium meeting in October of 2018 in Paris, and as a result he has been awarded to give this presentation.

Mr. Kauric is a second year Ph.D. student at the CEA Saclay in France in the Laboratory of Modeling of Thermodynamics and Thermochemistry. His Ph.D. research aims at investigating the chemical interactions between the mixed oxide fuel, fission products, and sodium for the safety assessment of the sodium-cooled fast reactor. In case of a severe accident, as the chemical system contains many elements, the CALPHAD method approach is the most suitable to develop a model for this safety study.

The first year of his Ph.D. was spent at the Delft University of Technology in the Netherlands and he investigated the fission products-sodium interactions. He is currently doing the second year of his Ph.D. at the Joint Research Centre in Karlsruhe on the experimental study of the sodium-MOX fuel interaction. And finally, the last year will be done in the CEA Saclay to build a CALPHAD model on the different systems under study. His research activities are funded by the CEA and also by the European Nuclear Education Network Plus Program. They are based on the multidisciplinary approach combining experimental work and modeling. In 2017, he graduated from *Chimie Paristech* ENSCP with a Diploma of Engineering option Chemistry of Materials and from the INSTN with a Master's Degree in Nuclear Engineering option Fuel Cycle.

Thank you so much, Guilhem, for volunteering to give this webinar and I give you the floor. Thank you.

Guilhem Kauric

Thank you for this introduction and good morning or good afternoon, everyone. Welcome to my presentation about the interactions between sodium and fission products in case of a severe accident in a sodium-cooled fast reactor. But before starting, I would like to thank first the Generation IV International Forum to give me the opportunity to do this presentation on the work that I have achieved during my first year of Ph.D. in TU-Delft in the Netherlands under the supervision of Anna Smith.

So I would also like to thank Anna Smith; also my Ph.D. Director, Christine Gueneau, working at CEA Saclay; and also Rudy Konings and Karin Popa, my supervisor in JRC-Karlsruhe in Germany where I am here right now.

I will start this presentation with a description of the context of my Ph.D. topic. Then I will explain what is the CALPHAD method and why this semi-empirical method is relevant for my study. But to understand this technique, you need some basics on Gibbs energy models. And finally, I will show you how to get input data for the modeling. So input data about structure, phase diagram, or thermodynamic. And of course at the end, I will conclude.

Let’s start with the context of my Ph.D. topic. My work is about sodium-cooled fast reactors. Here, you have a scheme of the sodium-cooled fast reactor. I will not go into details on how this reactor is operated because previous webinars were describing it. But for my study, there is one point that is really important, and that’s here. The core is cooled with sodium and so you have the fuel pellets that we can see here, the cladding, and then just after the cladding you have the sodium. I was talking about the fuel pellets that this design of reactor uses mixed oxide fuel, $(U_{1-x},Pu_x)O_2$ with a plutonium contents between 20% or 30% in weight percentage of plutonium.

And the irradiation, the fission of this heavy atoms, will release energy and create what we call fission products compounds or fission products. Moreover, during this irradiation, there will be restructuring of the pellets as we can see here, for example, with formation of a hole in the middle or some cracks over there in the whole pellets, and this will have an effect.

The fission products formed can be classified in different families because every fission products will have its own behavior and you can distinguish four families. The first one is the fission gases and other volatile fission products like iodine for example. You have also the fission products forming metallic precipitates like molybdenum or tellurium for example. The third family is the fission products dissolved in the fuel matrix like strontium. And finally, the fission products forming oxide precipitates like cesium, barium, molybdenum, and tellurium.

There is a very large thermal-gradient between the center of the pellets that can be like 2000 degrees Celsius and the outskirt of the pellet that is generally around 650 degrees Celsius and this will induce the migration of volatile fission products towards the cold parts of the fuel pellets. And, there, they will recondense forming what we call the Joint Oxyde-Gaine layer so mainly formed by cesium, molybdenum, barium, tellurium, and oxygen. As we can see here in this layer, so here we don't have any uranium or plutonium but the main compounds are cesium, molybdenum, oxygen and the most thermodynamic stable phase there is the Cs_2MoO_4.

Another phase can be found in the irradiated fuel called the grey phase, which is barium and strontium combined with zirconium, molybdenum, uranium, and plutonium and oxygen 3. These phases will be really under study during this presentation.

Here is a scheme of the different thermodynamic stable phases and their operation for the cesium, barium, molybdenum, and tellurium which are all the elements that we will focus on along this work.

Now that you have an idea of what we have inside the irradiated fuel, thanks to thermodynamic calculation, we can start with what will happen during a severe accident.

Let's start with the definition of what is a severe accident. A severe accident is happening when the reactor fuel is significantly damaged with more or less extensive melting of the reactor core. Here, you can see a scheme of one scenario of a severe accident called the total inlet blockage. This type of accident starts with a blockage of the inlets of the cooling system. Therefore, there is no more flow of sodium and only after 2.5 seconds the sodium will start boiling, and, after 4 seconds the vaporization is total. And just a few seconds later, you have the clads so the barrier between the sodium and the fuel, that will start melting. And then, only after 10 seconds after the beginning of the accident, the fuel will start melting and to end up with what we call a boiling pool where after only 15 seconds the steel will start boiling.

Depending on the scenario, you can have this type of boiling pool or fuel ejection into sodium. Therefore, you can have interactions between sodium and fission products compounds that we saw previously, but also interaction between sodium and mixed oxide fuel, and volatile fission products release.

Today, this talk will be focused on the sodium-fission products interactions because that is what I have studied during my first year of Ph.D. But now, in JRC-Karlsruhe I am currently studying the sodium-mixed oxide fuel interaction.

As I was saying previously, you have different scenarios. You can find three different types of severe accident scenarios. The first one called the Unprotected Loss of Coolant, ULOF, is where the sodium is biphasic for some periods before total vaporization. Then you have also the Unprotected Transient Over Power, UTOP, where there is a slight increase in the sodium temperature. But what is important is it is still liquid and the Total Inlet Blockage that I showed you in the previous slide where the sodium quickly vaporizes.

Moreover, when you describe severe accidents, you have to take into accounts two time scales. The first one is the short-term effects where you have to control the mechanical energy release during the accident in order to avoid the break of the confinements [ph] and the release of radioactive materials in the environment. You have also the long-term effects that deal with the management of the core after the accidents. In fact, you have to be sure that a fission reaction will not start again after the accident.

Therefore, the scope of the study is really the safety assessment of the sodium-cooled fast reactors with different axis [ph]. The first one is the sodium-mixed oxide fuel and fission products interaction at all stages of a severe accident. You also have to assess the consequences of a complete loss of the fuel pin tightness, so what’s happening when you have a boiling pool of irradiated materials. You have to answer basically two questions: which fission products are released, and is there an interaction with sodium?

And finally, you have also to manage the molten pool formed after the interaction between sodium and the irradiated fuel in a severe accident scenario. So basically, which compounds are formed during the cooling down of the core.

More practically, during this Ph.D. project, I am studying cesium, strontium, barium, iodine, tellurium, molybdenum, uranium, plutonium, and oxygen and all these systems in interaction with sodium. Just by saying this we can understand that it is a real complex system. And moreover, you have to study it on a large range of compositions and temperatures, from 600 to more than 3000 degrees Celsius.

Therefore, there is a huge need for thermodynamic modeling of the interaction between the fuel, fission products, and liquid sodium at the different stages of a severe accident scenario. In fact, the final goal is to describe the effect of temperature and oxygen potential on the interaction between sodium and the different fission products compounds. Because, in fact, these two parameters are key factors for the phase [ph] formation in the systems.

And to develop this thermodynamic model, we will use the CALPHAD method. What is the CALPHAD method? This technique provides a thermodynamic description of the system and this thermodynamic description can be used to calculate its chemical properties and it is based on the minimization of the Gibbs energy of the gas, liquid, and solid phases, as a function of the temperature, pressure, and composition of the system. But of course before going further on the CALPHAD description, I will introduce what is the Gibbs energy of a system.

The Gibbs energy can be defined by the enthalpy H here which represents the heat content of a system minus the temperature multiplied by the entropy of the system which has for a physical meaning, the randomness of the system. In thermodynamics you have a lot of relations. And thanks to this, you can also express it with the internal energy of the system, which is basically, the kinetic and potential energies of your atoms.

This G function is really the key function in the thermodynamics of materials because you can describe the evolution of your system with this and derive the equilibrium state of your system. In fact, at constant temperature and pressure, a closed system will be in stable equilibrium if it has the lowest value of the Gibbs energy. And in this point we have the derivative of G that is zero. But as we can see here on this diagram, it’s possible that sometimes you have different states, different equilibrium where the derivative of G is zero but only one will be at the lowest value. And this one, so A, is the lowest possible value of G, so this is the stable equilibrium; whereas B is what we call a metastable equilibrium state because the derivative of G is zero but it’s not the lowest possible value of G. Also, this G function is really useful in the thermodynamics relations because you can derive many other quantities thanks to the G function.

In the new system, in case you have several phases, the total Gibbs energy is obtained by linear combination of the Gibbs energies of each phase, and therefore you have the principle of the CALPHAD method, that is to optimize the G function of each phase by a least square minimization method to match the experimental data in order to be able to model your whole system. And as we are basing our modeling on the experimental data, this is a semi-empirical method.

But in new system you are also taking into account liquid phases and so we also need to model the Gibbs energy. And of course a liquid cannot be modeled as a solid because the constituents have no fixed environments and also the number of nearest neighbor can change in liquids. I will not go into details but you can describe the G function for liquids with three terms. So, one term called the G reference, another term called the G ideal, so this is if you have a liquid that is taken as an ideal solution so there are no interaction between the compounds in solutions. And what we call a G excess that is representative of these interactions with an interaction parameter L. You can see on the different graphs that this interaction parameter is really, really important because, for example, if you put a negative parameter, you have stabilization. But if you put a positive parameter, you have phase separation and you can see that the shape of the curves are totally different, so phase separation with the formation of two phases, so BCC1 and BCC2 are the two phases formed with the phase separation.

Just to have a more visual idea of what is the CALPHAD method. Here, you can find the experimental parts, so the experimental data. You can get, as I was saying in the introduction, experimental data from structure, phase diagram, or thermodynamics. And the structural data will help us choosing correctly the model of your system in your modeling.

And the phase diagram data and the thermodynamics data will help you in the model to optimize the parameters and get the G functions of your different phases that you will store in a database. And this database, you will use it then to perform some calculation, so all kinds of applications that you can have. And then, which is super nice, you can feed your experimental data also with the modeling parts. But at the beginning, there is a huge need for experimental thermodynamic measurements, because otherwise you cannot build your model.

We have a database called the TAF-ID that is an international project where many binaries and ternaries are reported. In the green, you can see all the binaries or ternaries that are reported in this TAF-ID project. We can see that almost all binary systems have been modeled whereas the ternary phase diagrams are missing except we have Cs-Mo-O, Ba-Mo-O, and U-Pu-O. So these are some of the very important phase diagrams for the study of the system. However, in this database, the sodium is not included. Therefore, I had to perform some literature review on the sodium system. And again, we have the same conclusion. Many binaries are modeled but only a few ternaries. We have the sodium-uranium-oxygen system that is also really a key system for the study and the sodium-molybdenum-oxygen system.

Now that we know what we have, we can start performing experiments to get some data for the CALPHAD modeling. So now, I will show you how to get experimental results to feed your model and then your database.

We will start with the barium-sodium-molybdenum-oxygen system. If you remember, at the beginning of the presentation I was showing you some phases that are stable in the irradiated fuel. And the two phases, BaMoO3 and BaMoO4 are found in the irradiated fuel, so the three dissolved in the grey phase and the BaMoO4 in the raw oxygen. However, there is no thermodynamic data on the interaction between these phases and sodium. But we have some CALPHAD models available that are barium-molybdenum-oxygen, sodium-molybdenum-oxygen, and barium-sodium. So we would be able, with some experiments on the quaternary phase diagram, to get the modeling of this phase diagram.

One quaternary compound was reported in the literature which is Ba2NaMoO5.5 but only structural data were reported. Therefore, we decided to synthesis these compound by solid state synthesis at 800 degrees Celsius under dry oxygen starting from barium molybdate, barium carbonate, and sodium carbonate, to get the pure compound and then to perform then the thermodynamic measurements. When you do a synthesis like this, the first way to control the purity of your sample is from the X-ray diffraction method. In fact, we obtained crystalline materials and this type of materials are made of repeating planes that you can see here in all directions and they can be described with what we call a space group and cell parameters.

When X-rays are heating the sample, depending on the incident angle, they will be scattered or not. And by collecting the scattered X-rays, you can get a pattern that is like this usually, that is really a fingerprint of the material. Because then on this pattern you can perform what we call the Rietveld refinements of your pattern and this will give you the space group and lattice parameters of your sample. As we can see here, we cannot see any additional peaks, therefore the compound was really pure.

Then we also performed some neutron diffraction measurements. For the neutron diffraction, it is exactly the same principle as X-ray diffraction but you are using neutrons instead of X-rays. Therefore, the neutron will be scattered by the atomic nuclei and not the electronic density surrounding the nucleus. And thanks to that, you can see really the atomic positions of the light atoms. So that’s what we performed. And, again, Rietveld refinement to get them and you can see that no additional peaks were found.

Finally, another method has been used on this compound called the X-ray absorption spectroscopy. The absorption of X-rays at a specified energy induces the ejection, that you can see here, of an electron from the core. And this is corresponding to a jump in the absorption curve. And this jump is characteristic of the oxidation state of the chemical element. We performed this for our quaternary compounds. And also, you need some references with the different oxidation states, so here is zero, here is 4, and here is 6. And thanks to these references and the measurements of other quaternary compounds, we found out that molybdenum was 6 in this structure.

Combining all this information, X-ray diffraction, neutron diffraction, and X-ray absorption spectroscopy, you can have a precise determination of your structure like this. So this is really how the crystal looks like in our quaternary compound with sodium, molybdenum, and barium atoms, and oxygen. And, thanks to this structure representation, you can choose the appropriate sub-lattice model for the CALPHAD modeling which is basically how you will model your structure in the software. As I was saying, the purity of the sample was good enough for thermodynamic measurements, so we performed some.

Before, we did some high temperature X-ray diffraction measurements, it was just to see how the compound was swelling and to know the evolution of the compound with the temperature. So you just had the time to see quickly the graph. But the curve for the quaternary compound was way more important than for the ternaries, so this has to be taken into account in the thermodynamic safety calculations.

Then we performed what we call the standard enthalpy of formation measurements with solution calorimetry. For this, in fact, you put some sample in an ampule that you put then in the reactor vessel and then you will crush it like here. And, in fact when the compound is dissolving, you release an energy by the dissolution reaction. And this energy can be measured with the calorimeter. However, to measure it precisely, you need first electrical calibration and also a second electrical calibration. Then you have the energy release of one reaction and then you can perform a thermodynamic cycle using just basic math to obtain. This reaction is called the reaction of formation of the quaternary compounds, and this enthalpy will be the enthalpy of formation of your compound. But, of course, to get this you have to measure all the enthalpy of reaction of all your reactions, so 1, 2, 3, 4, and 5 and then you can sum them to get it in the end.

Now, we'll just do a quick recall on the CALPHAD modeling. You can find again the G function that's expressed differently, like with the standard enthalpy of formation so here is the H term. And this is what we measured with our quaternary compounds. You have also the standard entropy. So the S term multiplied by T, and also what we call the heat capacity. As I was saying previously, the G function is – you have a lot of relation using the G function. That's why all the measurements are useful like standard entropy measurements, heat capacity evolution at high temperature, low temperature, melting temperature, phase diagram data, enthalpy of melting. Well, the more experimental data you have, the more accurate modeling you will get and this is really a key point of the CALPHAD modeling.

Now that I showed you how to get some input data about the structure, I will explain to you what I will do in my last year of Ph.D., on one of the models, the barium-sodium-molybdenum-oxygen system. To build the CALPHAD model, the first step is to model the binary sub-systems. This, as we showed in the table, is done. Then the second step is to model the ternary sub-system, so here, for example, between barium oxide and molybdenum-O3. So this is nearly done, we have some models but some are missing. Then the third step is to model the quaternary system. At each step, you have to determine the G function for all the compounds and the interaction parameters for the solutions, which is a lot of work.

Now, let's go on the second system, the one with cesium-sodium-molybdenum-oxygen system. Why are you interested in cesium? This fission product is very volatile and it has an important radiological impact on the environment if released. So, you have to know what's going to happen to the cesium in case of a severe accident. You have two quaternary compounds in this system so we did exactly the same structural measurements but I will not detail them here. I will focus more on the study of the pseudo-binary phase diagram Cs_2MoO_4-Na_2MoO_4. In fact, Cs_2MoO_4 is the main phase expected in the Joint Oxyde-Gaine and, therefore, in case of a severe accident, you could have a substitution of sodium into this Cs_2MoO_4 or a reaction between the sodium and these compounds. Moreover, on the pseudo-binary phase diagram Cs_2MoO_4-Na_2MoO_4, one of the quaternary compounds exists on this pseudo-binary. So you had two reasons to study this and it will be used to build the CALPHAD model also.

To study to get to the phase diagram data, we used differential scanning calorimetry measurements. Basically you put your sample here with a reference here and you will heat them at the same time at the same temperature. Here, you have a picture in a more real way. If something is happening to your sample like phase transitions, eutectic, or liquidus transitions, you will release energy again. And this energy you will see it's here on the heat flow measurements where you will have a peak like this, for example. So this is a typical DSC measurement of a mixture of Na_2MoO_4-Cs_2MoO_4 in this ratio. And you can see that you have two phase transitions, one eutectic and one liquidus here.

We performed several measurements with different compositions of Na_2MoO_4-Cs_2MoO_4 and so we obtained what we call the experimental pseudo-binary phase diagram here between Na_2MoO_4 and Cs_2MoO_4. What we have to assess with this is, so is there a miscibility gap here? And this type of measurements will be used to build the CALPHAD model and get also a lot of information about the interaction terms 'L' between the liquids.

Now, I will go on the examples of application of the CALPHAD models. Because when you have your database, then you have to use it to make some, for example, phase diagram or calculations.

First, I will talk about the database because this is what we are building. In this database project which involves Canada, France, Japan, the Netherlands, Korea, UK, and the USA, you have 41 elements that were inside this database, with 206 binaries and 76 ternaries. Again, a lot of binaries are known but only some ternaries. When you have this database, you can model some systems like, for example, the Cs_2MoO_4-MoO_3 system that is also one of the systems that is really a key system in my study. This is pseudo-binary phase diagram and you can have also ternary phase diagram like here between cesium-molybdenum-oxygen. And there you can choose a temperature here and know which phase is stable at this temperature in the function of the composition of your system which can be really useful.

Also, you can perform calculations on irradiated fuel with, for example, following the evolution of secondary fission product phases between 1500 kelvin and 3500 kelvin. Here, you can recognize one family of fission products called the metallic precipitates, so the ones that are metals. You can see here that they are stable at 1500 kelvin. But when you are starting to increase the temperature, they will melt and the melting happens at 2100 kelvin. But also, you can find what we call perovskites. That is, if you recognize the formula, the grey phase that I was talking about before. And you can see that they will melt at nearly 2500 kelvin, but what is important to look at is that you will have a liquid forming. Therefore, you will have the dissolution of the fuel matrix in the molten perovskites. Locally, because these types of compound are just local in the fuel, you will have the beginning of the oxide fuel melting. And the melting of the fuel matrix is really at a lower temperature than expected locally.

To conclude, the study of such complex systems and wide physico-chemical conditions requires thermodynamic modeling of nuclear fuels to have more information about oxygen potential, fission product phases, solid/liquid transitions, heat capacity, and vaporization of species, all what you need to know more about the behavior of the irradiated fuel in case of accidents, for example.

CALPHAD is a suitable method to model these multi-component systems by extrapolation from binary and ternary sub-systems. However, it is time-consuming, therefore, you need international projects to develop large databases. Moreover, you need to validate your databases, and for this you have to do experimental thermodynamic measurements on the fuels that are really challenging. And to develop the databases, you can use the first-principle calculations as I showed you before with the G functions and how to express the G functions with other terms to find some input for your models.

In our database, so the TAF-ID, many systems are known but there is no model for sodium systems. Therefore, the aim of my work is to obtain a model for the sodium-fission product systems. But this is not the only system that I am focusing on during my Ph.D. I am also studying, experimentally the sodium-uranium-plutonium-oxygen system in JRC-Karlsruhe here in Germany and I will perform the same kind of measurements to develop in the end a thermodynamic model for these quaternary systems also.

Thermodynamics alone cannot explain the fuel behavior. It has to be coupled with kinetic and mass transfer models. And that’s why we are currently working on it with the SIMMER fuel performance code and the Open CALPHAD and the TAF-ID database.

I will finish my presentation with acknowledgements to my Ph.D. Director, Christine Gueneau again, to Anna Smith and to Enrica Epifano. If you want to stay in touch, I put here some links about the TAF-ID project, CEA in France, TU-Delft in the Netherlands, JRC-Karlsruhe in Germany but under the European Commission. If you want to know more, just go check these links or send me an e-mail at my e-mail address that is on the second slide. Thank you for your attention and I think I’ll give you back the lead.

Berta Oates
Thank you, Guilhem. If you have questions for the presenter today, please go ahead and type those into the questions pane. And while those are coming in, we’ll just take a quick look at the upcoming webinar presentations scheduled. In July, a presentation on the Security Study of Sodium-Gas Heat Exchangers in the Framework of Sodium-Cooled Fast Reactors; in August, a presentation on Lead Containing Mainly Isotope Lead 208: New Reflector for Improving Safety of Fast Nuclear Reactors; and in September, a presentation on the Gen IV Coolants Quality Control.

So, Guilhem, are you able to see the questions pane? There’s a question…

Guilhem Kauric
No.

Berta Oates
Not in the chat pod but in the questions pod, there’s a question reading, I am sorry for the out of topic question, just want…

Guilhem Kauric
No, I don’t see the questions.

Berta Oates

…according to you, the fuel has thermodynamic equilibrium during irradiation in normal conditions and accident scenarios.

Guilhem Kauric
No, because that's why I was saying that you need to couple with kinetic and the fuel codes because the time scale is really, really short, so you cannot be in a thermodynamic equilibrium. Actually, you will form the phases, so this is what we call the thermodynamic stable phases. And of course you have to assess that these phases are possible to form thanks to PIE, Post Irradiation Examination.

For example, Cs_2MoO_4 was said to be the most stable phases in the Joint Oxyde-Gaine and really recently it has been demonstrated that this phase is present in the fuel. So thermodynamic equilibrium depending on what's your definition of equilibrium.

But, for example, then if you also look at how to manage decorum, so the long term effects, there you have a way longer time. So, there the phase that is almost stable, thermodynamically speaking, should be present. But again, you have to assess it with Post Irradiation Examination.

Berta Oates
Thank you. Is there a similar study for MOX fuel with lead coolant?

Guilhem Kauric
This I don't know. Because I am not working on lead coolants, so I don't know.

Berta Oates
There's a question asking for your e-mail. I'll remind folks it is shown on the Meet the Presenter slide, the second slide in today's presentation. The handouts are available in the handout slide pane. You can download those right down. And Guilhem if you want to just say your e-mail then everyone would have it verbally.

Guilhem Kauric
It's my first name dot my surname. guilhem.kauric@cea.fr.

Berta Oates
How do you choose which fission products are important, for example, why ruthenium is not included?

Guilhem Kauric
Because we really focused on this cesium while on the volatile fission products and then what we could have in the Joint Oxyde-Gaine. So we decided not to include the ruthenium because we had to choose. That's it. Like it would be really interesting to study the behavior of the ruthenium.

But unfortunately, we had to make some decisions so we started with the system cesium and barium because we had the modeling of the CALPHAD model for the cesium-molybdenum-oxygen and the barium-molybdenum-oxygen.

Berta Oates
Hang on one second, we've got an e-mail. I apologize. I've received an e-mail from someone who is not able to see the questions pane. It seems, by your explanation, that the effect of an accident with sodium-cooled fast reactor is rather complicated to find out. Is it still reasonable to do this much research into sodium-cooled concepts? Would it also apply to the dual fluid reactor concept?

Guilhem Kauric
Can you repeat the question? I didn't get it.

Like if I understood correctly…

Patricia Paviet
Berta, we do not understand. It's going too fast.

Berta Oates
Let's see if I can put it in the chat pod for you.

Guilhem Kauric
Like if it was worth it to study the sodium-cooled fast reactor?

Berta Oates
I've typed it. I've copied and typed it into the chat pod, not the question pod but the chat pod because I can't access the question pod.

It says it seems by your explanation…

Guilhem Kauric
The problem is with many, many reactor systems that are chosen by the Generation IV International Forum to understudy, you have to assess the severe accident consequences. And in severe accidents, we are heating at a very high temperature and you need to do research to find out what is happening. And so I think yes because this type of reactor is really interesting as you can really close the fuel cycle. And of course if it was easy to find out what was happening, it wouldn't be research. So I think it is totally reasonable to do this.

Berta Oates
Great. Can you use this model to identify the chemical forms of radionuclides?

Guilhem Kauric
Can you repeat a bit slowly please?

Berta Oates
I am sorry. Can you use this model to identify the chemical forms of radionuclides?

Guilhem Kauric
Okay. So it's chemical forms of radionuclides. Well, I would say yes, because you can see the phases that are formed, so your element will be like, for example, metal or combined with oxygen. And this, from the phase diagram you can see the phases that are the most stable under these conditions. So, yes, I think so.

Berta Oates
Thank you. Do you think to include also elements from cladding as a next step?

Guilhem Kauric
Yes. There are other Ph.D. students working on this type of interactions but my Ph.D. is really focused on cesium, barium, molybdenum, tellurium, strontium, uranium, plutonium, and oxygen. It's already a lot of work. So yeah. But yes.

Berta Oates
Thank you. Have you found xenon to be a strong neutron absorber or poison?

Guilhem Kauric
On the nurturing [ph] part, I don't know but I can check later on if you send me an e-mail. Because I was really focusing on building the thermodynamic model, so getting input data for the modeling part and that's why we want also to do a coupling with the fuel performance codes to have more information about the behavior of and the irradiation because they need the thermodynamic data as input also.

Berta Oates
Thank you. Great questions. I don't see any additional questions. So I'll take this minute to thank you again, Guilhem, for your time and effort in putting this presentation together. Congratulations on great acknowledgement. As a reminder to people, he's a second year student and so we look forward to the great things that he will contribute upon graduation and you can see that he has a very bright future.

Guilhem Kauric
Thank you.

Berta Oates
I don't see any additional questions so I think that will conclude today's topic and presentation. Thank you all for your participation and attendance and good day.

Patricia Paviet
Thank you, Guilhem. Thank you, Berta.

Berta Oates
You are very welcome. Bye, bye.

Guilhem Kauric
Okay.

Patricia Paviet
Bye. Bye, Guilhem. Bye bye, Berta.

Guilhem Kauric
Thanks. Bye. Ciao.

END