Czech Experimental Program on MSR Technology Development
Dr. Jan Uhlíř, Research Centre Řež, Czech Republic

Berta Oates
Doing today's introduction is Dr. John Kelly. John is the Immediate Past Chair of the Generation IV International Forum and the former Chair of the International Atomic Energy Agency, Standing Advisory Group on Nuclear Energy. John also has the distinctive position of being the first webinar presenter in our webinar series, and he has experience. He's now retired and had a distinguished career through the US Department of Energy. John.

John Kelly
Thank you Berta and it's my great pleasure to actually welcome Jan to the webinar series. We've known each other for several years going back to when I was at DOE, but he's now a Senior Researcher at the Research Center Rez, and he has been working closely with the molten salt reactor technology, and he's led several national programs devoted to molten salt technology. Jan is a representative of The Czech Republic in the Working Party on the Scientific Issues of the Fuel Cycle of the OECD-Nuclear Energy Agency, a member of the MSR Provisional System Steering Committee of the Generation IV program as a representative of EURATOM and a member of the High Scientific Council of the European Nuclear Society. Jan earned his MS in chemical engineering and Ph.D. in nuclear fuel technology at the University of Chemistry and Technology in Prague. So yeah, my colleague, please.

Jan Uhlir
Okay. Thank you very much for introduction, John. Ladies and gentlemen, good morning in America, good afternoon in Europe and very early morning in Eastern Asia and Australia and good very late afternoon in Western Asia. It is a pleasure for me to provide you by information about the Czech Experimental Program on molten salt reactor technology development, which plays the important role in our domestic nuclear development activities. The Czech Republic is a relatively small country, but we are active in nuclear and nuclear share in our county is about 35%. We are active in this area, and we also plan to increase the nuclear power in the Czech Republic.

Moreover, all our reactors were made by Czech industry. Therefore, we realize that we need to be active also in the development of advanced nuclear technologies and the MSR technology was selected as very promising for us. Beginning of our activities reaches practically the second half of 90s and our first approach in this area was motivated by the effort to utilize this technology within the partitioning and transportation systems. It was quite attractive in the second half of 90s to be involved in this system. Originally, they believed that the combination of accelerator-driven technology and liquid fuel could be the suitable solution for the incineration of transuranium elements and long-lived fission products from spent nuclear fuel.

The first studies of this system – I mean, this subcritical molten salt, the first studies were done in 1998 and the year after in 1999, we submitted our first proposal to the Ministry of Industry and Trade of the Czech Republic.

Next slide please. The first activities were initiated by Dr. Miloslav Hron. You can see him in the picture. He practically obtained some good experience in this area because he spent some time in the Los Alamos National Laboratory, and when he returned, he then led the Czech molten salt program through the whole first decade of the century. For us, the big motivation at the beginning was organization of the ADTTA99 conference, which was held in Prague, Pruhonice. And we had a chance to discuss our program with several distinguished scientists who attended the conference. I mentioned some of them here in the photograph. I would like to mention Alvin Weinberg, Charlie Bowman, [Unclear] and David Williams from United States, Vladimir Prusakov from Russian Federation, famous person in the fluoride technology. And Peter Wilson from United Kingdom who also helped us to understand thorium-uranium fuel cycle. From the Czech side here, I have two names, Dr. Ivo Peka who was the founder of Czech nuclear fluoride technology research and for sure Milo Hron.

Next slide please. Our proposal to open the national project was accepted by the ministry in 1999. And the Ministry of Industry and Trade began to support these activities in 2000. Right from the start, the R&D activities included also significant experiment program. The program took full advantage of the opportunities offered by the nuclear research center in Rez where research and experimental nuclear reactors have been placed side by side with radiochemical complex and fluorine chemistry laboratories. For an experimental MSR program, this is I guess the ideal combination.

Next slide. However, the Ministry of Industry and Trade had just from the beginning a strong requirement for us that the research must be realized in collaboration with our Czech nuclear industry. So therefore our MSR projects were always solved by consortium of Czech research institutions and industrial companies. I have here the list of the main organizations and companies involved in the consortium just from the beginning. So it was UJV Rez, formal name, Nuclear Research Institute. It was original leading company. Then Research Center Rez, which is present leading company. COMTES FHT. This is methodologic research and development company. Energovyzkum Brno, Institute of Nuclear Physics of the Academy of Sciences. This Academy of Sciences was involved only relatively in the beginning of the period when we were involved in the subcritical systems. And then Faculty of Nuclear Sciences and Physical Engineering, Skoda JS. This is Skoda Nuclear Machinery. This is the producer of all nuclear reactors in Central Europe, I mean in the territory of Czech Republic, Slovakia, Hungary, and the company MICo.

Next slide. Just from the beginning, we made some experimental program also focused on the subcritical systems, but approximately in 2004, we practically abandoned this idea to continuing development of subcritical systems and all our activities practically identified ours with the idea of molten salt breeder reactor as it was proposed by Oak Ridge. Also, I would like to mention that we discussed our program also with John Richard Engel and Mctod [ph] from Oak Ridge who visited Rez in 2002 and who gave us valuable practical advice.

I hope you know that Ho [ph] participated in molten salt reactor experiment in 60s and Dr. Engel was chief engineer of the whole project.

Just from the beginning, we are involved in the development of several areas. We contributed to the knowledge to reactor physics, core design and safety of structure and structural material development and also to the technologies which are applicable within the molten salt. On the line reprocessing and we were also involved in the verification of other materials area and so and so.

Just from the beginning, we saw two important projects. It was the project Sphinx and then fluoride processing, and we also were involved in the activities of some international organization like also Euratom International Atomic Energy Agency, and we also contributed to Generation IV as representatives of Euratom.

To the main experimental activities in molten salt reactor physics and neutronics. It was investigation of MSR physics which was focused on the experimental measurement of fluoride salt neutronics at the LR-0 reactor and LVR-15 reactor in the Research Center Rez.

Basic principles of the method of measurement were successfully verified and selected neutronics data of several fluoride salt mixtures containing uranium and thorium were obtained by irradiation of so-called instrumented probes, which were inserted into the central part of LR-0 reactor core where the standard VVER fuel assemblies surrounded this core served as neutron driver. Here you can see the pictures of the LR-0 reactor core drawings with the position of individual fuel assemblies and in central part the inserted zone with some material of testing, typically also the molten salts. And on the picture on the right, there is the experimental channel which was put usually in the central part of the reactor instead of one fuel assembly.

To the next slide. Here, I would like to inform your also about the experimental activities devoted to the fuel cycle technology. Here, the development of thorium-uranium fuel cycle covered both the verification of MSR liquid fuel reprocessing and the laboratory investigation of online reprocessing technology. I am now speaking about the activities during the first decade of this century. You can see in the pictures our production of uranium tetrafluoride, thorium tetrafluoride, preparation of liquid samples for the subsequent measurement of neutronics in reactors. Those green samples are a mixture of the carrier salt, typically lithium and beryllium salt [Unclear] with uranium tetrafluoride and the picture on the laboratory studies in our laboratory in UJV mainly.

Please, next slide. In the next slide, I would like to inform you about the activities in the development of structural material. Because Hastelloy N was not available for us, we decided to develop own nickel alloy for molten salt technologies and we asked Skoda Nuclear Machinery and later on also the COMTES company, and we asked them to develop own nickel alloy suitable for this technology, I mean for molten salt reactor technology. You can see the composition of our original nickel alloy, which is called MONICR, and we produce it just experimentally. We produce it experimentally also today. Approximately in 2011, we would say that we have own nickel alloy, MONICR. Okay.

To the next slide please. Some important milestone was in 2012. Our experimental program in MSR physics and neutronics was limited by the fact that we did all experiments and neutronics measurement with FLiBe salt, which was composed from lithium fluoride with natural lithium. We had no lithium-7 fluoride and our experiments were practically devaluated by the presence of lithium-6 isotope, which is in natural lithium.

However, thanks to our scientific contacts with our US colleagues, mainly with Professor Peterson from University of California, Berkeley; Charles Forsberg from Massachusetts Institute of Technology; and David Holcomb from Oak Ridge National Laboratory. We opened the discussion about the collaboration in the development of MSR and FHR. And our common proposal was that Oak Ridge National Laboratory will provide us by original FLiBe coolant salt, which contains a highly pure lithium-7 isotope and that we will do our neutronic experiments with this salt. In 2012, the Ministry of Industry and Trade and US Department of Energy signed memorandum of understanding, and based on this memorandum of understanding, in 2013 we obtained about 75 kilogram of the molten salt reactor experiment coolant salt from Oak Ridge.

The year after, we started our experimental program. And from 2015 also, our Oak Ridge partners, Oak Ridge researchers, participated in the evaluation of the measured data. Here are the photos how we discussed it at the US Department of Energy and photos from transport of the salt, then the preparation of the salt for the experiment and view into the core of LR-0 reactor's decontainer with this salt containing lithium-7. FLiBe with lithium-7 is used only for neutronic experiments in the Research Center Rez and in the UJV Nuclear Research Institute.

Now, I would like to inform you about the present activities. The present program is a followup and the broadening of existing Czech activities in MSR and the new MSR project was approved by Ministry of Industry and Trade in 2016 and program is running from 2017. And the program is now granted by the Technological Agency of the Czech Republic.

Here, the present program is also solved by the Consortium of Czech Research Institutions and Industrial Companies. And also it has quite an important area in the experimental research. Here is the list of the members of the consortium. One change was that the current project Research Center Rez, my company is the leading company of the program. But I would like to inform you that Skoda Nuclear Machinery and Company MICo are very important members of our consortium and both are the companies of Czech nuclear industry.

Next slide please. The present project has following work packages. This is molten salt reactor physics and salt neutronics, molten salt fuel cycle technology, development of structural materials for fluoride molten salts, molten salt reactor and fluoride salt high-temperature reactor material studies. This includes also the molten salt loop program and development of the components suitable for molten salt reactor and fluoride high temperature salt reactor technology. And finally also, some basic studies including non-proliferation issues and physical protection, it is a part of our studies of the thorium-uranium fuel cycle.

And for sure, for us the continuation of the collaboration with US partners and this memorandum of understanding is important.

The next slide, let me do comment some results achieved in molten salt reactor physics and salt neutronics. In the picture and photo in this slide, you can see the scheme of the LR-0 reactor and the view into the reactor core. Here, we measured several neutron spectra in graphite and in selected fluoride salts, I mean the salt FLiNa, it is sodium fluoride, lithium fluoride mixture. FLiBe with natural lithium at the beginning and later on FLiBe with lithium-7 and also the spectra of fluorine because our colleagues found that there are some wrong data in the database about fluorine. So, to measure fluorine spectra we used Teflon blocks as measurement of gaseous fluorine would be practically impossible in the reactor.

The existing measurement in the reactor – I mean the salts were done at the room temperature because we had no suitable equipment till now to realize the measurement at the high temperature, typically the temperatures of the molten salt reactor working range, I mean from 500 to 750. But we plan to do it next year.

Please, next slide. In this slide, you can see how we prepared the inserted zone for the neutronic measurement with FLiBe. The zone on the pictures here has a special container which is filled with hot FLiBe from the transport container, which we obtained from Oak Ridge. The method of how to fill it is by siphoning effect. And then after the salt became cool, it was instrumented and put into the experimental channel of the reactor and was then placed into the center of LR-0 reactor core. As I mentioned till now, all measurements we made in LR-0 was done at the room temperature, so it means the salt inside the container was solid.

However, now we started a program to measure the FLiBe neutronics at temperature range corresponding to real temperatures of molten salt reactor.

Please, next slide. How we plan to realize that? Because it is impossible to have heating system inside the reactor. It is impossible as concerning the reactor safety, as concerning the practical experimental measurement of neutronics and criticality and so on. So, our choice how to heat the salt is described here. First, we need to preheat. It will be new FLiBe container, much bigger than the former one. We must preheat the new container or the salt inside the new container outside of the reactor in some oven to about 800 degree centigrade. And then we will insert the container into one vessel and then into the experimental channel. And because this container will be surrounded by insulation vessel, so the whole system or whole set will be much more bigger and will be in the reactor instead of seven fuel assemblies.

Finally, when the experimental channel with the FLiBe container will be inside the reactor, we start pumping the water into the reactor because the reactor reached the criticality by increasing of the water level. Here, I have the information that's the series of measurement will be done at several temperatures reached by gradual cooldown of this salt in the container and in the reactor and the typical time for individual experiment will be about 2 to 3 hours. So, we will be in a hurry and now it is quite a very big challenge for us.

Well, in the following slides you can see how it will look, this container. Here is some set of the equipment of the container, and you can see the different temperatures inside the container, and the maximum temperature of the water in the reactor, the maximum temperature should be below 60 degrees centigrade. Here, we calculated that for 57 degrees centigrade.

At the next slide, you will see schematic design of individual parts and how the parts will be operated, will be moved one into the second tier. FLiBe model will be done from the nickel alloy INCONEL 625, then will be thermal insulation. The third is cylindrical vessel from stainless steel, and the last one, the biggest one, will be aluminum heptahedron we call it, and this will be put into the reactor.

On the next slide, there is more detailed drawing of this set. Yes. This is here. In the next slide, please, here is the view into the reactor and here is drawn the placement of this polyhedron vessel for FLiBe in the central part of the reactor that it is instead of as I mentioned seven fuel assemblies. Okay.

Here is one more slide about the current status. Today, present status is that the zone and other components are now manufactured in our workshop in Research Center Rez, and it was necessary practically significantly adapt the bottom part of the reactor LR-0 core. Concerning the plans, we believe that the manufacturer of this new zone will be finished before this Christmas and then after the approval, which we need from the state office for nuclear safety, we plan to start the cold experiments in the first quarter of 2020 and the hot experiments in the second quarter of next year, of 2020. As I mentioned, this is now a big challenge for us. And for sure, this experimental program you can imagine is relatively quite costly.

Now, I would like to move to the information about our activities in the area of thorium-uranium fuel cycle. We focused on the investigation of electrochemical separation technologies from molten fluoride salt media. The carrier salt for molten salt reactor working in thermal spectrum is FLiBe. However, the lithium-beryllium mixture, lithium-beryllium eutectics is insufficiently electrochemically stable and therefore we had to serve how we should do the electrochemical separation. We have to find some more stable carrier salt for electro-separation and that's lithium fluoride, calcium fluoride eutectics.

In the picture, you can see the electrochemical potential which were measured by UJV Rez for individual separation of uranium, thorium, and some lanthanides and FLiBe and in lithium fluoride, calcium fluoride. For your information, the electro-separation method we used is linear potential sweep cyclic voltammetry.

Next slide. Here is information about our development of reference electrode because there is no standard reference electrode for electrochemical measurement in fluoride media. This is the difference if we compare it with chloride media. And therefore, we had to propose own design of the reference electrode based on the electrochemical couple, nickel 0, nickel 2+. These are right now studied by UJV Rez and UJV now also collaborates with the University of Wisconsin-Madison to investigate the long-term stability of the electrode because the stability is time-limited.

In the drawings and pictures here, there are schematic designs of reference electrode, electrode set and photos of the electrode surface. And here inside the circle, you can see some small interaction of metallic nickel with the surface of the electrode body. After some time, it can negatively affect the long-term stability. But for all that, this type of reference electrodes seem to be probably the best one for the fluoride media.

Concerning the next slide is information about the actual work and future plans in electrochemistry. We would like to focus now on quantitative separation of uranium from some lanthanides, typically uranium from gadolinium because most of other lanthanides were just measured. And also for updating the rules for nickel/nickel 2+ reference electrode usage. And in collaboration with Joint Research Center Karlsruhe, we would like to open the studies of electrochemistry of protactinium, and therefore, we just practically finished the preparation of our alpha hot cells, so we will do that in Research Center Rez in our alpha hot cell. Okay.

To the next slide please. Okay. Information about the current status of structural material development and components for salt reactor technology. As I mentioned earlier, the company COMTES developed the nickel alloy MONICR, and this is the present project COMTES continues in the further development of MONICR alloy, in the verification of semi-pilot production. Today, they are able to produce ingots of the maximum weight 600 kilograms. They plan to measure mechanical stability to do creep test, radiation embrittlement, and to study the behavior. I also have here the present task, the influence of hot deformation on recrystallization at high temperatures. Okay.

At the next slide, you can see the information about the activities of the company MICo, which is focused on the development of flange gasket system for the connection of pipes of molten salt technologies. This is quite a serious problem how to connect by the flanges the tubes with molten salts at high temperatures. On the slide, there are photos and pictures showing the principle how we test the closeness of individual designs of flanges gasket system. We typically test it with FLiBe salt at the temperature of 600 degrees centigrade. This is our standard temperature for testing of flanges gaskets. Okay.

To the next slide please. In 2017, we built our FLiBe loop which should help us to do some corrosion tests of selected structural material samples, not only of MONICR but also other nickel alloys and other materials. And for our information, the loop is made from INCONEL 718 alloy, and it contains also the freeze valve and a relatively primitive pump. The loop has about 6 liters plus the volume of the dump tank and it is heated by electric power.

At the next slide, you can see the photos of the loop, how it is placed in the laboratories, in the fluoride laboratory of the Research Center Rez. From the safety reasons, the loop is placed in the box which is connected with chemical of gas system with special [Unclear] and so and so.

The loop program, as I mentioned, is intended to the material components tests and subsequently in some future also from the thermal hydraulics experiment and verification of thermal hydraulics code data.

At the next slide, there will be activity done by Skoda Nuclear Machinery. This is also important part of our project. This is development of pumps for fluoride salt medium. Skoda Nuclear Machinery is responsible for the development of impeller for molten fluoride salts. You can see some photos of this impeller, which is now under development and under some preliminary test. And we would like to also finally test this impeller in our loop, so we hope we will do it during next year.

To the conclusions, our program is in the long run focused on experimental development of selected areas of molten salt reactor technology, which can be also partially applied for fluoride salt-cooled high-temperature reactor systems. However, as I mentioned, the Czech Republic is a relatively small country and has no ambition to build now our own molten salt reactor. But we would like to contribute to the development of this technology and we would like to be a good partner for those countries or companies, which will build and deploy molten salt reactor system. As the Czech Republic intends to continue in the utilization of nuclear power and to increase its present nuclear share, the country wants also to appropriately contribute to the development of advanced reactor technologies. Present state support of the development of MSR technology should create the condition for Czech companies to be among the suppliers of selected parts of molten salt reactor technology.

Here, I would like to finish my presentation and I thank you for your attention. Thank you.

Berta Oates

Thank you Dr. Uhlir. If you have questions, please type those into the question pane. And while those questions are coming in, we will just take a quick look at the upcoming webinar presentations that we have scheduled. In December, a presentation on TRISO fuels by Dr. Feltus. In January of the new year, a presentation on thermal hydraulics in liquid metal fast reactors by Dr. Gerschenfeld. And in February a presentation on SFR safety design criteria and safety design guidelines by Mr. Kubo.

I don't see questions coming in just yet. If you have questions, please do type those into the Q&A pod. Again, thank you Dr. Uhlir. I know that we've had quite a bit of effort putting this presentation together and I apologize for the technical issues that we have experienced today. But I think the presentation was well received, and I appreciate all of your efforts to volunteer to put this presentation together.

Jan Uhlir
Thank you to all listeners.

Berta Oates
There is a question. Is there cooperation between the Czech side with the Swiss PSI and the MSR research?

Jan Uhlir
Yeah. Concerning our collaboration between the Paul Scherrer Institute in Switzerland and the Czech Republic, Research Center Rez is also involved in a European project. Today, the new project which started here is the project [Unclear]. This is our platform for the collaboration with other European institutions and other European countries. But concerning some direct bilateral collaboration, it doesn't exist. This is only exchange of scientific information. We have several friends in Paul Scherrer Institute, but there is no contract between Paul Scherrer Institute and for example UJV for Research Center Rez.

Berta Oates
Thank you. In a sort of a followup type question, what are the areas of research under development in molten salt reactors worldwide?

Jan Uhlir
The current status of the molten salt reactor research is that the absolutely most active are our colleagues in China. Chinese Shanghai Institute of Applied Physics is responsible for the building of molten salt reactor. They call it thorium molten salt reactor. The reactor should be finished at the end of next year. This is in Wuwei city. This is in Northeast China. And the Chinese have a, we can say, fantastic program and there are several thousand people involved in this program. China is practically today number one, and for sure we collaborate under the

umbrella of Generation IV International Forum under the Provisional System Steering Committee of Molten Salts.

Here, members are United States, Euratom, France, Switzerland, Australia and also of course China and Japan. Some of them are only observers, but we also collaborate under this umbrella. But China is today the only country, which is just building the molten salt reactor.

Berta Oates
Thank you. Are there any other questions out there for Dr. Uhlir? Again, I want to thank you for taking the time to join us and participate in the GIF webinar presentations and our thanks again to today's presenter Jan, thank you very much for your efforts in putting this presentation together and for your work in this area.

Jan Uhlir
Thank you to have a chance to have this lecture for Gen IV.

Berta Oates
Okay. Bye-bye.

Jan Uhlir
Okay. Bye, bye, bye. Thank you. Bye, bye. It was my great pleasure.

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