The ALLEGRO Experimental Gas Cooled Fast Reactor Project
Dr. Ladislav Belovsky

Berta Oates
Welcome everyone to the next Gen IV International Forum webinar presentation. Today's presentation is on 'The Allegro Experimental Gas-Cooled Fast Reactor Project' by Dr. Belovsky. Doing today's introduction is Patricia Paviet. Dr. Paviet is the Technical Group Manager of the Radiological Materials Group of the Nuclear Sciences Division at the Pacific Northwest National Laboratory. She is also the Chair of the GEN IV International Forum Education and Training Taskforce. Patricia?

Patricia Paviet
Thank you. Good morning everybody. We have Dr. Ladislav Belovsky with us today. He works at the UJV Rez close to Prague, Czech Republic, as a senior engineer and he has over 30 years experience in nuclear energy research. He graduated from the Czech Technical University of Prague in 1988 as a Master Scientist in Mechanical Engineering for Nuclear Industry. And he received also his Ph.D. in 1993 at the same university for 'Modeling of Light-Water Reactor Fuel Behavior in Severe Accidents.' Since 2011, the main area of his research activity focuses on the development of Gen IV reactors.

Dr. Belovsky participates in the development of the helium-cooled fast reactor ALLEGRO in the frame of the international association V4G4 Center of Excellence in the following areas: Design and Safety of the reactor, Related R&D focused on safety, helium technology and material research. His background in the Czech Republic as well as in France in the period between 1988 to 2011 is mainly characterized by activities in the development and application of computer codes for modeling of Light-Water Reactor fuel behavior in design basis and severe accident conditions. Thank you so much Ladislav and I give you the floor. Thank you.

Ladislav Belovsky
Good morning to everybody. I am Ladislav Belovsky and will give you details on the development of the small demonstration unit of a gas-cooled fast reactor. The work on ALLEGRO started in France. And then it was passed to Central European countries of the Visegrad 4 group. I will tell you something about the motivation, why ALLEGRO, about its philosophy. I will speak about the recent developments, and touch also the R&D which is now underway on ALLEGRO and will conclude speaking about our plans and perspectives.

As there is no gas-cooled fast reactor running in the world today, there is a need to build first a small demonstration unit of course just to establish the confidence in the GFR technology. The goals of the demonstration unit are listed here on this slide and are these four ones. As users of the potential large gas-cooled fast reactors for industry expect to have a safe large industrial unit using high temperature resistant refractory fuel, the demonstration unit should be used just to verify, validate, and test this type of fuel. To demonstrate that we are able to have control over the reactor to prove that it works safely and get experience with the gas-cooled fast reactor related technologies, which are associated with the refueling, with the helium purification, and other technologies.

Of course, one very important part will be to prove that the integration of all the individual features works well in a representative system. One of the major points is to show that a small GFR is safe. So, we will have to prove, validate, and provide to the nuclear reactor community a safety reference framework. Currently, for this moment there is no power conversion system planned for this demonstration unit.

Last year my colleague from CEA, Dr. Alfredo Vazel [ph] gave a webinar on the big GFR2400 pre-conceptual show design prepared in France at the CEA. ALLEGRO will touch all the challenges concerning the high-temperature resistant fuel, safety, fuel handling and so on. But there is one very important point in addition to all these blue ones, which insists in the use of currently existing fuel for the driver core which is based on the current SFR technology coming from the sodium-cooled fast reactor. I will explain it on the next slide.

The philosophy of ALLEGRO is to start in the following way. As we don't have for this moment validated the high-temperature resistant fuel being able to withstand the target temperatures of the coolant around 800 degree C, we will start with loading the driver core composed of, let's say, ordinary oxide fuel in stainless steel tubes, the design coming from the Phenix sodium-cooled fast reactor in hexagonal geometry. And due to the limitations of stainless steel, we will have to limit the core outlet temperatures to something slightly above 500 degree C.

When having in the future first a [Unclear] or fuel assemblies of the high temperature resistant refractory fuel composed of the carbide mixed fuel in silicon carbide based tubes, we will load one up to six of these fuel assemblies into the prepared positions and irradiate. These test fuel assemblies will be able to reach the target coolant temperatures at the outlet being in the range of roughly 800 degree C thanks to reduced flow rate going through these test fuel assemblies.

After mixing with the coolant from the driver core fuel assemblies, the average core outlet temperature of the primary helium will be again limited to roughly 530 degree C. When having the refractory fuel well approved for full scope operation, then the final full refractory core will be loaded, and ALLEGRO will be able to operate at the target temperature around 800 degree C. It means that all of the technology around which can't be replaced, must be designed from the very beginning for the high-temperature option.

This slide shows the history of the development of the demonstration unit which started roughly in 2002 in France at CEA. Our French colleagues first prepared a pre-conceptual design of a small, so-called experimental technology demonstration reactor, 50 megawatt thermo. This was available in 2008. The next stage which came 1 year after was characterized by increased power and in fact a very similar layout. Details will follow on the next slide.

The main characteristics of these versions are the following. The ETDR was composed of one primary loop and water on the secondary side. ALLEGRO has two primary loops also within water on the secondary side. As it was realized that gas would be more appropriate to be used in the fast reactor, then another version was introduced by our CEA colleagues, which was characterized with a turbo machinery in the secondary circuit to enhance the safety.

In 2009-2010, this project was passed to Central European countries from the Visegrad 4 group. Since then, we are continuing the development. First, a Memorandum of Understanding was signed between research organizations and industrial companies from Hungary, Czech Republic, and Slovakia. In 2013, an umbrella association so-called V4G4, Visegrad 4 for Generation IV Center of Excellence, was established in Slovakia. This is a legal person under which the development of ALLEGRO is now being performed. There are four core members and two associated members from France, CEA, and the Research Center Rez, Centrum Vyzkumu in Czech language, from Czech Republic.

This slide indicates the first version of ALLEGRO at the time called the ETDR which was characterized by one primary circuit, reactor pressure vessel, coaxial piping into the gas water heat exchanger. These three coaxial pipings are emergency cooling circuits for the case when the ordinary cooling through the secondary circuit is not possible. The philosophy used and taken by our French colleagues was to quickly forward and to use all the possible technology which is available in the world. This is why the helium water-heat exchanger was proposed just to speed up the development.

This technology is being used in Japan in the HTTR graphite-moderated helium-cooled reactor. The parameters of this reactor were in the first stage going slightly over 500 degree C when using the oxide fuel-based in stainless steel tubes for the driver core, and slightly above 800 degree C when using the full ceramic core.

The layout of the facility can be seen here. Many details were developed at the time. Some of them only in an indicative way. Some technologies were developed not at all or very roughly.

In the meantime, our French colleagues realized that two main primary circuits, main two loops in the primary circuit would be a more safer solution. To improve the long-term economy, the core was made larger and the power increased from 50 to 75 megawatts thermal. The ALLEGRO, which was and is the base, the ALLEGRO pre-conceptual design prepared by CEA in 2009 can be seen on this slide. We have here in the central part the reaction pressure vessel, the two primary loops with the helium water heat exchangers. Here in the bottom, we have the main blowers. Here we have three Decay Heat Removal, DHR heat exchangers in the top using the chimney effect in the case of primary natural circulation. Here you can see the Decay Heat Removal blowers. This red component is an optional gas-gas heat exchanger which was proposed to use the heat from the primary circuit for technological purposes.

Here you see the small demonstration unit ALLEGRO and on the right side the large industrial reactor for generation of electricity, as demanded by EDF nearly 20 years ago. Dr. Vazel last year gave a webinar on the GFR technology and spoke in detail about this target unit. Today we see that the progress is moving towards smaller reactors. Probably the market will demand smaller units. Maybe our target unit will not be a big industrial GFR but a medium or small module reactor with roughly 200 megawatts thermal. Regardless of this, we have to prove the safety and viability of the GFR technology through the development and commissioning of the ALLEGRO reactor.

Here are parameters of the ALLEGRO pre-conceptual design by CEA from 2009, very similar to the ETDR, the option with the driver core inlet temperature 260 and average core outlet temperature of the helium coolant 530. In case of the full refractory core, we will reach temperatures around 800-850 degree C our plant, with 400 degree C inlet temperature to the core.

Here you can see the secondary circuit composed water and secondary circuits of the Decay Heat Removal loops consisting also from water. It is important to say that the power density of both concepts is around 100 megawatts per cubic meter, which is roughly more than 1 order of magnitude, maybe 20 times more than in graphite moderate helium-cooled reactors like HTTR or others.

As the GFRs were being developed since early 60s, at that time the success was limited by poor safety of the proposed concept. There was, in fact, very big trouble with loss of coolant accidents. There was practically no way to avoid core melting. To overcome this deficiency of gas-cooled fast reactors, our French colleagues introduced a concept of a so-called Guard Vessel. A closed envelope around the primary circuit which would enable a so-called backpressure in the case when the primary coolant escapes from the primary circuit just to assure a pressure in the breached primary circuit and around well above the atmospheric pressure. In this case, when the inventory of the primary circuit escapes into the Guard Vessel, the backpressure stabilizes at around 3 to 4 bars, which reduces substantially the pumping work of the active systems of the blowers and so on.

Another option is to inject another gas, for example, nitrogen, into the primary circuit just to increase the backpressure from 3 or 4 bars to roughly 10 or more, just to make the coolant more dense and provide conditions suitable for the natural convection. This option to plant in ALLEGRO CEA 2009 was not fully available. The safety in this concept was assured by active systems using forced convection. This was in contradiction with the VENRA [ph] IEA and the GIF requirements of safety just to use passive systems as much as possible. Here it is to note that the internal concrete superstructures of course are shown in the figure just to make the primary circuit visible.

This is a detail of the Decay Heat Removal heat exchanger which shows the way of the hot helium rising through the coaxial Decay Heat Removal loop, and then going down through the water-cooled piping of the heat exchanger. But unfortunately in this case, the gas is obliged to pass through the Decay Heat Removal blower which represents a very large obstacle for the flow in case of natural circulation. This is one of the features which had to be modified, and next versions overcame this problem.

Another problem here is the use of the U-tube concept where the cold water first continues from the top to bottom and then back. In case of troubles with the cooling on the water side, bubbles could appear which would cause instabilities in this component. Again, this nice piece of work will have to be redesigned just to avoid this potential source of instabilities in case of troubles with the flow on the water side of the DHR system.

Here this slide shows two types of valves used in the system. Here in the bottom part you see the longitudinal cross section of the primary heat exchanger with the blower on the bottom side with the water here attached. Here at this location there is a set of six disk valves which are open when the primary blower is blowing and providing flow. When this blower is stopped, these elements just close the openings and there is no flow through the primary loops. This upper part shows a similar type of disk check valves in the Decay Heat Removal heat exchanger. These valves assure no flow through the DHR loops during the reactor operation.

Here you see the core, the first core layout, the driver core which will be used for commissioning of ALLEGRO. The yellow hexagons are the MOX fuel assemblies. The red and black are control and shutdown assemblies. The green assemblies are the positions where the experimental red fuel assemblies containing the refractory fuel can be loaded. Here you see the target parameters at that time of the large industrial GFR as proposed by CEA in 2005 or 2006. Here are the parameters of ALLEGRO which should be as close as possible to this large industrial unit. I mean especially the fluence [ph] and the neutral flux which is quite comparable to the big GFR. The fuel cycle length was chosen to be 660 years and no core load was assumed. Just the core should be replaced one by one.

Here is a more general figure which shows the core which we were speaking about just on the previous slide with the reflector assemblies, shielding assemblies, and the intermediate shielding made of stainless steel which fills the space between the hexagonal shape composed by the core reflector at shielding and the core barrel. Here is in fact the down-comer and around is the reactor pressure vessel. Here you see the details on the driver core and on the refractory core. As you can see, in the first core there would be really a lot of stainless steel.

The stainless steel is one of the limiting factors concerning the outlet core temperature just because the melting temperature of stainless steel used for this. The structure element is something above 1300 degree C. This slide shows details of the MOX fuel pins and assemblies very similar to the Phenix design.

This slide indicates the details of the refractory fuel. Here is to point out that we still come with mixed carbide fuel pellets located in silicon carbide based tubes. It is one of the concepts, one of the technologies today planned also to be used in PWRs or even sodium-cooled fast reactors. So, our colleagues in the world work hard on this. This technology one day should be able as a basis for the ALLEGRO refractory fuel to be loaded into these three or six experimental positions to be irradiated and tested.

One of the important features of the experimental ceramic fuel assemblies is thermal shielding which is designed to protect the neighboring driver core oxide based fuel assemblies using stainless steel as structural material. Here inside the refractory fuel assemblies, the outlet core temperature, outlet fuel assembly temperature would be roughly 800 degree C, and the outlet coolant temperature from the neighboring driver core fuel assemblies would be, as I said previously, something roughly above 500 degree C. After mixing of these two flows, so maximum 6 experimental fuel assemblies with 800 and something degree C and 500 and something from the driver core fuel assemblies, the resulting average coolant temperature just above the core would be again something above 500 degree C.

The safety is one of the most important aspects of ALLEGRO. This is the DHR strategy, the strategy to remove the Decay Heat Removal in case of loss of flow accidents, loss of coolant accidents. You can see in case of protected accidents when the reactor is successfully shut down that first the cooling will be provided by the primary blowers when possible. When not possible, the active systems in the Decay Heat Removal loops will be used to remove the decay heat by forced convection from the core. The natural convection is planned to be used only in pressurized condition.

Here in this whole domain of loss of coolant accidents with primary coolant pressure below the nominal one, the design relies on forced convection as the main phenomenon to be used for the removal of the decay heat, which is of course not good. What concerns the unprotected transience, it is similar to other fast reactors like SFRs. Of course, the GFR is characterized by pressurized coolant. Unprotected transients associated with complete loss of coolant from the primary circuit should be practically eliminated. This will be an issue in the design of any GFR included ALLEGRO.

Here is the last version of ALLEGRO as proposed by our French colleagues at CEA in 2010, which was patented. The goal of this proposal was to improve the safety, to assure cooling in any protected transience, pressurized or depressurized. The idea is based on the use of the turbo machinery in the secondary circuit, this time filled with gas, helium for example. Here you see a gas turbine, helium turbine, helium compressor. The main idea is to connect the turbo machinery in the secondary circuit with the primary blower. It means, after shutdown the primary blowers would be temporarily operated by thanks to the mechanical inertia of the turbo machinery. And thanks to the thermal inertia, it will be operated for a certain time. Analysis show up to 50,000 seconds the primary blower could be – the countdown of the primary bloomers could be extended after roughly 5000 seconds which is sufficient to evacuate the decay heat in the initial periods when it is large.

Here we can say that this represents a kind of a passive way of the Decay Heat Removal. But it is technically quite very complicated to be assured as there is no such technology available in the world which will be used to assure safety of ALLEGRO. Another issue would be to pass the shaft through the closed envelope, through the guard vessel which encloses the primary circuit. But this is just one of potential ways how to improve safety of ALLEGRO.

Here we can see that the mechanical and thermal inertia can save the core even in case of large break LOCA and even when only one turbo machinery is running in the system. Two peak cladding temperatures over time when both turbo machineries are available, and the peak cladding temperature when only one turbo machinery is available. Peak cladding temperatures are quite well below the stainless steel melting temperature and temperatures when the fuel can be pressurized.

Here are listed the advantages and disadvantages of this solution. It is technically very complicated. And one of the most important aspects is when the turbo machinery stops in passive operation, it cannot restart again.

This slide lists the open issues of the pre-conceptual design which concerns the operational conditions. As you know now there is water on the secondary side of the primary circuit and also in the secondary side of the Decay Heat Removal circuit. There is a risk of water ingress through the DHR heat exchanger into the primary coolant. At this moment, we are unable to isolate the DHR loops from the rest of the system. In case of use of water, on the secondary side of the primary circuit there would be an uncontrolled risk of water ingress into the primary circuit of a fast reactor which seems to be quite dangerous. The disk check valves were up to now tested experimentally. And as I mentioned, the isolation valves for coaxial piping either DHR or the main piping connecting the reactor pressure vessel and the main heat exchanger are not available. It is also a technical challenge. Other issues are listed here and are associated with the ordinary mechanical engineering. But refueling machine does not exist. There is no design in the route for this type of technology. Heat shielding above the core, which would isolate the hot flow from the reactor pressure valves is also to be designed and tested. This is also a challenge in GFR and so on.

Open issues in accident conditions comes mainly from the stainless steel based fuel assemblies. The peak cladding temperature in any kind of accident must be limited to temperatures well below this melting temperature of the stainless steel, which is a quite technical challenge. So, the keyword today of the safety of ALLEGRO is to ensure the core coolability.

We could reach it, for example, also by reducing the power characteristics, the thermal power just to minimize the decay heat. But the irradiation characteristics of ALLEGRO would then also be reduced.

One of the issues is the Decay Heat Removal in passive mode, how to ensure the Decay Heat Removal when there is a station blackout and no active system is available. For example, by promoting the natural circulation in the system, by maximizing the driving force using as high a pressure in the guard vessel as possible, so feasibility study is now being performed to see whether such a large structure can be build and resist to pressures slightly above 1 megapascal. Of course, the local flow resistance in the Decay Heat Removal system must be minimized, for example, bypassing the DHR blower in natural flow mode.

Another issue is to provide the Decay Heat Removal heat exchanger resistant to high temperatures. This is the design based criterion as by CEA. It should withstand such high temperatures for more than 30 minutes. An extensive R&D is now going on, on this issue.

In 2010, the activities at CEA were passed to the Central Europe. The association called V4G4 Center of Excellence was established in Slovak Republic with the aim to provide umbrella for further development in this part of Europe. The technical base was chosen to be the ALLEGRO CEA 2009, which I was speaking about on the previous slides. Here you see the industrial and the academic partners in this association coming from Slovakia, Czech Republic, Hungary, and Poland with the responsibilities listed here. Associated members are providing either technical consultancy or R&D infrastructure. Here are the years when these members became associated to V4G4.

The new ALLEGRO V4G4 concept, its goal is to provide a safe concept use based on passive safety and solve all the questionable features of the mechanical engineering which were mentioned concerning the valves, the heat exchangers, and all the GFR-related technologies which are not existing up to now which are a big challenge also to us.

The efforts in the ALLEGRO CEA 2009 concept were focused on the neutronics of the core, on the fuel, and on assuring the core coolability using active systems mainly. All the remaining auxiliary systems were addressed marginally, which is quite understandable. Our French colleagues wanted to progress fast and to solve the most important elements of the design. When we reviewed this concept, we realized that to make the new concept safe and feasible, we have to make some important modifications. First, not only to make it closer to the big GFR concept which today is becoming obsolete due to the trends to smaller units. We wanted to remove the water from the secondary circuit just to exclude by design the possibility of criticality due to water while ingressing into the primary circuit, and maybe one day using the concept which was mentioned using the turbo machinery to provide some inertia for the Decay Heat Removal.

The concept of passive or semi-passive systems is very important for us. We are trying to assure the coolability of the core by passive systems only, using the natural circulation of the primary helium as much as possible.

Another feature is associated with the oxide fuel in the driver assemblies. Potentially enriched uranium might be used and replace the mixed oxide fuel. This is still open. When decided, the ALLEGRO core would have to be larger just because of the limitation on the concentration of the U-235 to less than 20%. The reason is just well known, the nonproliferation condition.

But in our case, it would result in roughly having the power density in the core and having the core roughly twice as large. In our case, we have to focus also on the GFR related and helium related technology because we have to provide a really feasible concept from any aspects. We will have to provide solution for all the auxiliary systems even if they seem to be routine as the helium gas storage systems, makeup systems and so on. But the solution to – but the accidents, there is not enough space around the primary circuit as there is the [Unclear] we will have to touch all the auxiliary systems just to be able to draw the concept and provide complete solution of this problem.

Here is the overview of the time schedule of the development. Here you see just the year 2009-2010. The moment when our French colleagues started the negotiations with Central European Institutions, 2013 establishment of the V4G4 Center of Excellence. And roughly from 2015, the ALLEGRO development was restarted in Central Europe with the goal to provide the pre-conceptual design in 2020 and conceptual design in 2025 roughly.

Here in the books called R&D I would like to point out the commission of two helium loops which will be crucial and important for ensuring safe design in case of loss of flow or loss of coolant accidents in passive mode. A helium loop commissioned in Slovakia, a simple helium loop dedicated to studies of natural circulation and a more complex loop in Czech Republic which is going to start its operation this year.

This slide indicates the elements of the design and the design steps which are characterized by the design basis. For the reactor and all the systems, it provides the input for design, then safety requirements, design and safety roadmap, and ALLEGRO business plan. The preliminary design will start with the core and fuel neutronics and simple development of the primary circuit and the associated Decay Heat Removal system.

The guard vessel is the integral part of this process. Of course, the preliminary design will be assessed by analysts to show whether it is compliant with all the VENRA [ph] and GIF and IEA requirements. At this stage, the R&D requirements, the requirements for associated research and development should be formulated also in this stage.

This is an extended version of the previous slide when having the preliminary design already available with proven characteristics, in this case, we can start the development also of the auxiliary systems because we well know, the main characteristics of ALLEGRO which should not change substantially.

Here is shown the progress which was made recently. Here are shown the peak cladding temperatures in a small break LOCA aggravated with station breakout. So, it means Decay Heat Removal in passive mode in case of 1 inch loss of coolant accident. The previous CEA 2009 concept reached melting temperatures in the cooler very quickly. In our case, when the concept of the optimized Decay Heat Removal system using optimized natural circulation using the bypass of the primary blower. And in addition, the injection of the heavy gas nitrogen, for example, pressurizing the guard vessel to pressures slightly above 10 bars, above 1 megapascal. The peak cladding temperatures are kept well below 800 degree C which is a very good result for which we are very happy. At this moment, the nitrogen accumulators would send additional flow of nitrogen into the system.

Here we see a similar picture in case of large break LOCA characterized with fast depressurization. So, in 2 or 3 minutes the original concept would reach stainless steel melting in the core. In our case, the introduction of the bypass of the Decay Heat Removal blower would already well prevent the melting of stainless steel in the core. And in association with the injection of nitrogen into the core, individually introduction of bypass and individually introduction of the nitrogen injection into the system. This is the integral – these are the peak cladding temperatures when both elements are used, the bypass of the DHR blower and the injection of the nitrogen.

Here you can see that even if the primary coolant escapes completely from the primary circuit provided the guard vessel is tight, the peak cladding temperatures in the core would not reach even 1000 degree C which is very, very optimistic. Later in case of full ceramic core, this would represent very, very safe behavior of such a GFR. We are of course penalized somehow through the use of the driver core using the stainless steel. This is why we have to introduce very intensive safety systems and this is one of the possibilities how to reach the goal.

The R&D needed for ALLEGRO is listed here in very, very general way. We are now working on formulation of detailed items or details of the R&D items. Of course, the R&D on the safety of the oxide cores is associated with the system thermal hydraulics. The heat transfer in the fuel bundle could with helium for example which must be proven experimentally, feasibility of the guard vessel including core catcher issues and so on. R&D associated with the helium technology, just ordinary issues similar to those solved by our Japanese and Chinese colleagues in the graphite moderated helium-cooled reactors. But in our case completed with purely GFR related systems like fuel handling instrumentation and so on. We realized that the computational tools we are using must be validated and we have to be sure about their precision and validation domain. This is why benchmark activities were running in last years.

Material qualification of all the material used in the driver core and the refractory field assemblies, R&D concerning the reactor control from the point of view of materials, design, and so on.

And here, the thermal barriers is something which is also GFR related only, not needed in the graphite moderated reactors. This is what we will have to touch. And of course when having the fuel elements, we will have to qualify it somewhere in the world in any suitable fast reactor, for example, assemble the future material test reactor in Russian Federation which we hope we'll be able to use in the future.

I'm approaching to the end of the presentation. Here on this slide are shown the elements of research and development as proposed and partially realized in France in CEA. Something was designed, something was built but many, many stands and facilities were not put in operation. We are now going either to use them or build similar ones in the V4 countries.

The crucial element here is just to ensure the core coolability in passive mode.

Here it is listed – the R&D priorities are listed here on this slide. The priorities touch the validation of the DHR approach using both loops which I mentioned already. Then, the feasibility of the guard vessel resistant to elevated pressure. To provide the driving force for the natural circulation. And of course, elements associated with the heat transfer from wire-wrapped rods bundle into prototypic helium which is still not available in the world. Something was performed in air. Of course, there are stands and facilities for this kind of research in sodium. But we have to build and test the fuel bundles, fuel assemblies also in helium just to prove that our computational tools predict well the thermal or hydraulic behavior in the core.

This is the second part of the R&D priorities. Just quickly, feasible and safe nitrogen injection into the reactor pressure vessel. The expansion of the nitrogen is associated with important sub-cooling of the gas which could quite embrittle the structures when being touched with this flow. I spoke about the turbo machinery potential used in the secondary circuit. But this time not connected by a shaft but potentially driven but electrically thanks to the electricity generated during the rundown of the system, just to avoid passing the shaft through the guard vessel or catcher. Decay Heat Removal heat exchanger, able to withstand the high temperatures. This heat exchanger of course must not fail because this is one of the crucial elements for safety, valves and so on.

The R&D platforms we have are listed here. We have two helium loops which I hope will provide us data on the natural and/or forced circulation in the helium system. There are other helium loops available used for material research in the prototypical control atmosphere where we have the possibility to test either out of pile or in-pile in a thermal reactor a small pulse [ph] in prototypic atmosphere, 7 megapascal with doped impurities. There was knowhow gained in the helium purification issues recently. We have stands for that helium recovering from the guard vessel atmosphere is one interesting feature of GFRs which is not associated or related to the safety but to the economics of a potential large fleet of GFRs in the future.

If there would be an important number of helium-cooled reactors in the world then helium is a scarce commodity. Not easily renewable. It is not cheap. We started research on its recovery. When it leaks from the primary circuit and other technologies into the guard vessel, we would be able to recycle it back to the helium storage tanks just to minimize helium losses. And in this case, the GFR fleet would be much, much less dependent on the helium market in the world. Of course, we have not to forget the severe accidents and provide data on the material interactions in case of melting of the fuel and structural materials. We have facilities in Czech Republic cold crucible where we can reach large high temperatures. We can melt oxide fuel elements with the structural materials and observe the behavior of these couples.

I am approaching really to the end of the presentation. Here, you see the helium loop S-ALLEGRO in the Czech Republic which I expect will start to provide data this year, which will be built in two phases. Now we have the phase I available which is characterized with one primary loop and one DHR loop. In the future, we should have the configuration mirroring the ALLEGRO CEA 2009 concept with the same parameters as expected in ALLEGRO. Here you see the configuration which we expect we will reach in the future.

This is a very simple but already operating loop in Slovak Republic dedicated to studies in natural circulation. The heating section, then rising piping to the water-cooled heat exchanger and down back to the heated section with the maximum temperature around 500 degree C. This will allow us to master the knowledge on the natural circulation.

Here you see the R&D elements which we have for studies of the helium recovery from the guard vessel atmosphere. Today, we are working on a small scale facility to demonstrate that we would be able to recover the leaked helium from the nitrogen-helium atmosphere by either membrane or another technology.

Here is shown the cold crucible available in the research center in Czech Center, it's called CV Rez in Czech Republic.

The last two slides which would conclude the webinar on ALLEGRO, I would like to stress the following points. The sodium-cooled technology is well known in the world. Sodium-cooled fast reactors were and are operated in the world but helium-cooled fast reactors don't exist, and we are still in the phase of proving its feasibility and passive safety today.

The French concept is a good technical base which must be further improved and we are working on proving its technical feasibility from any aspect. And we are trying to assure the target mission of the demonstration. It means to be safe and providing the characteristics which were mentioned in the beginning of the webinar concerning the fuel, irradiation characteristics, safety framework and so on. We have applied a person, the umbrella association, which was established 6 years ago in Slovakia, the V4G4 Center of Excellence. It has no financial resources. The members have through either national research programs or Euratom-funded research.

The short term priorities are focused on the passive safety. Meanwhile, we are trying to prove feasibility of UOX-based driver core to provide ALLEGRO with this type of fuel if MOX would be not either possible or allowed in Central Europe.

The short-term priorities are listed here and they concern the coolability issues mainly in protected transients using passive systems, feasibility of the guard vessel, and all the associated issues, minimization of the low core resistances in the DHR system, valves and so on, turbo machinery when required. For this moment, it seems that the turbo machinery might not be needed as a safety qualified system but only for generation of electricity when needed.

We are still looking for some alternative cladding material for the driver core fuel elements. But as this would require an extensive R&D, we are trying to make ALLEGRO safety for these conditions trying to maximize efficiency of the safety systems. Of course, as mentioned already, the computational tools have to be either benchmarked, validated, or development must be assured in the case where the current tools are not able to touch either the design or conditions. I mean refractory fuel, for example, from the point of view of core degradation and so on.

At this moment, I would like to conclude the webinar. Thank you very much for attention. I would like to encourage you to ask questions. I will do my best to answer your questions. Thank you very much for attention.

Berta Oates
Thank you Dr. Belovsky. If you have questions for today's presenter, please go ahead and type those into the Q&A pod now and we'll take as many as we have time for. While those questions are coming in, let's take a quick look at the upcoming webinars.

In April, a presentation on European Sodium Fast Reactor: An Introduction. In May, Formulation of Alternative Cement Matrix for Solidification and Stabilization of Nuclear Waste. And in June a presentation on the Interaction JOG/Sodium in Case of a Clad Breach in Sodium Fast Reactor.

END