LA-UR

TITLE: "WHITE LAND"....NEW RUSSIAN CLOSED-CYCLE NUCLEAR TECHNOLOGY FOR GLOBAL DEPLOYMENT

AUTHOR(S): Dr. Charles D. Bowman

SUBMITTED TO

MASTER

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DISCLAIMER

"White Land"....New Russian Closed-Cycle Nuclear Technology for Global Deployment

Charles D. Bowman
Los Alamos National Laboratory

Abstract

A Russian technology called "White Land" is being pursued which is based on their heavy-metal-cooled fast spectrum reactor technology developed to power their super-fast Alpha Class submarines. These reactors have important safety advantages over the more conventional sodium-cooled fast breeder reactors but preserve some of the attractive operational features of the fast spectrum systems. Perhaps chief among these advantages in the current political milieu is their ability to generate energy from any nuclide heavier than thorium including HEU, weapons plutonium, commercial plutonium, neptunium, americium, and curium. While there are several scenarios for deployment of these systems, the most attractive perhaps is containment in submarine-like enclosures to be placed underwater near a coastal population center. A Russian organization named the Alphabet Company would build the reactors and maintain title to them. The company would be paid on the basis of kilowatt-hours delivered. The reactors would not require refueling for 10-15 years and no maintenance violating the radiation containment would be required or would be carried out at the deployment site. The host country need not develop any nuclear technology or accept any nuclear waste. When the fuel load has been burned, the entire unit would be towed to Archangel, Russia for refueling. The fission product would be removed from the fuel by "dry" molten salt technology to minimize the waste stream and the fissile material would be returned to the reactor for further burning. The fission product waste would be stored at New Land Island, their current nuclear test site in the Arctic. If concerns over fission product justify it, the long lived species will be transmuted in an accelerator-driven system. Apparently this project is backed at the highest levels of MINATOM and the Alphabet Company has the funding to proceed. The first deployment is planned for power-deficient Archangel. Apparently about seven of these reactors have been built and they report 80 years of reliable operation.....far more than any other fast reactor type. The initial fuel for these systems is 80 % ^{238}U and 20 % commercial or weapons plutonium, HEU, or other higher actinide mixture. Wide deployment of these systems would require all of the fissile material that exists in Russia so that it is unlikely that any of these materials would undergo geologic storage or be blended down. The company says that production facilities for these reactors exist and that it can supply such systems 2.5 years after contract. They tend toward the smaller sizes being available in units of 1, 5, 10, 50, and 200 MWe. Early potential foreign sites after Russian deployment include the Mediterranean and Sotheast Asia.

Introduction

During a visit in St. Petersburg, Russia from February 3-10, 1996 as a contract monitor for the International Science and Technology Center Project 17, I became aware of a concurrent meeting in the same building with the title, *First International "White Land" Chapter Conference, "Scientific and Technological Basis for Global Energy System," St. Petersburg, Feb. 4-7, 1996.* This meeting was being held in a meeting room directly across from the ISTC Project 17 meeting. Many attendees at the ISTC meeting attended the White Land meeting and some of the speakers presented papers at both. As a participant in accelerator-driven transmutation technology development, I have become acquainted with the nuclear fuel cycle including the various reactor types, approaches to recycling, permanent waste disposition possibilities, etc. and related issues such as weapons plutonium disposition. I was quite surprised at the scope of the "White Land" concept, its technical maturity, and the strong financial and political backing it appeared likely to receive. While this was primarily a "scientific and technological" meeting with only sketchy details about deployment, I was able to fill in enough detail from hallway conversations and from my own surmises to assemble a perhaps accurate and complete picture of the entire White Land Project. I will try to indicate in the course of this report that which is conjectural on my part. This report is backed up by attached material including a transcription of the notes I took at the meeting and by a few documents gathered at the meeting.

The story begins with the Russian effort to build a better reactor power plant for driving their submarines. While the original systems deployed were light water reactors, it was recognized early that fast spectrum reactors could operate at a higher power density than LWRs and therefore it was potentially possible to pack more power into a sub using fast reactor technology than the LWR technology. According to Dr. G. Toshinsky of the Institute of Power Engineering, Obninsk, Russia, another country first attempted to do this with a sodium-cooled reactor. That reactor was eventually replaced with a conventional reactor later owing to poor performance and the fires and other safety problems associated with the use of liquid sodium coolant underwater. He then described in some detail an effort to use a liquid lead-bismuth coolant with protection of the walls from corrosion by maintaining a protective layer of zirconium nitrate. He says that the program encountered problems in assembly when this protective layer would be damaged and in maintaining the layer after the reactor was operating. After long study the project was abandoned. The Russians followed a different strategy by using ordinary steel (as I understand it) and establishing and maintaining a layer of oxide on the surfaces for corrosion protection. This was a success and the first reactor was deployed in the first Alpha Class submarine in 1979. This submarine type apparently was built to operate at great speed and depth. In reading about this class of submarines in Jane's Fighting Ships it is said that these submarines could operate at 45 knots and at a depth of 2500 ft. Jane's also reports that seven or eight of these Alpha Class subs were built. Toshinsky reported that this sub's performance is listed in the Guinness Book of Records as the world's fastest submarine. The Russians at this meeting were obviously quite proud of this technical achievement and at having bested the U.S. in this fast reactor technology.

The purpose of the "White Land" Project is to deploy this reactor technology for commercial electric power and for heat production. These reactors do not have the problems of conventional fast reactors of the positive void coefficient or the problems with sodium fires. In addition the core can be made self cooling in a loss-of-cooling-accident quite readily particularly under the conditions of undersea operation. And in the case of accident, the fuel becomes encased in solid lead-bismuth so that "there is virtually no possibility for leakage of radioactivity." Throughout the meeting it was clear that the Russians believed that this system could answer virtually all of the safety and environmental concerns for nuclear power. In case of problems with the back-end of the fuel cycle and the implementation of separations technology which could be made environmentally and politically acceptable, the Russians have clearly borrowed heavily from the Los Alamos accelerator-driven molten-salt-based transmutation technology.

This meeting was run by the Alphabet Company located in Moscow which has been formed to market this technology. The president of the company is Dr. A. Drozdov. He is viewed as an "operator" in Russia having moved frequently among many technical positions including a stint at Chernobyl. The translator for the meeting, Boris Landa, is quite obviously a key player in the company although his role was never made clear. His addressed is listed as New York, USA. It was said that he has been present as a translator at Vice President Gore's recent meetings with the Russians. Dr. Victor Orlov, the most respected reactor engineer in Russia, and the leader of the development of the lead-cooled reactor also played a leading role in the meeting at many points. It is clear that this venture has been cleared at the highest levels in the Russian government; the list of attendees is attached. Dr. John Weeks of Brookhaven National Laboratory who had worked on heavy metal cooled reactors many years ago was the only person from the U.S. invited. He was unable to attend because of illness, but he told me in a telephone conversation after I returned that he did supply them with the transparencies describing his work of 30 years ago. In the beginning of the meeting, I felt somewhat like an intruder, but I seemed to be welcomed by the meeting and was included at a conference banquet and at the closing roundtable. The meeting was open in the technical sense but the plans on deployment and practical implementation were much more tightly held. I could learn nothing about the Alphabet Company except its address. It is my impression that the meeting in St. Petersburg which was mainly a technical meeting including a few key foreign visitors, was followed by a closed meeting in Moscow during the following week when deployment and implementation were perhaps discussed.

The first deployment of these reactors is planned for the Russian Arctic, where there is a severe power shortage, and probably at Archangel. I remember reading about the temporary supply of power to Archangel by a submarine a few years ago while a power plant was undergoing repairs. The intent would be to supply electric power and also heat for the city. From the title of the meeting however, it is clear that the intent is to deploy these systems worldwide as ocean based power systems. Therefore it would seem that the intent is to deploy first in Russia and then in other countries.

Reactor-Technology and Fuel Cycle

It appears that the reactor works very well and that for the Russians it is a bird-in-the-hand. The Russian lead is of course enormous in this type of reactor and it would seem to be at least 10 years before any other nation in the world could match it. The Los Alamos National Laboratory has been working with Sweden to apply the Russian molten heavy metal technology to neutron-producing targets for the accelerator-driven transmutation systems. A contract is almost in place with the Obninsk Laboratory where this molten lead-bismuth technology was developed to build a liquid lead-bismuth target for testing in the LANSCE beam stop at Los Alamos using the full 1 megawatt average power of the 800-MeV LANSCE beam. The funding of about $1 million for design and construction is being supplied by the Swedish Accelerator-Driven Transmutation Program. The first $30,000 of these funds is to pay for patents which the Russians will place before the technology is released. The target for LANSCE will arrive at Los Alamos in 2.5 years. The Los Alamos Accelerator-Driven Transmutation Technology Office is providing the technical oversight for Sweden and for Russia. Some oversight funding also is provided from PSI in Switzerland and more might be available soon from the European Union and Japan.

These lead-bismuth-cooled reactors, which are no longer new, apparently have been adapted well to the submarine configuration. They produce no external waste and work well with only maintenance required outside of the fissile material containment. It is said that the main health concern is the ingestion of polonium and that this never reached unsafe health limits in the early version of these subs, but that since the beginning of deployment the amount of ingested polonium has been greatly reduced. Since the reactors can operate for 10-15 years without refueling, their up-time should be excellent. The operation and maintenance crew requirement must be modest since it certainly requires no more than can be carried on the Alpha Class submarine. If these systems are deployed underwater, both shielding and passive coolant issues are simplified. These reactors probably can be placed in refurbished retired submarine hulls or the steel from them can be refabricated into the underwater containers for the reactors. Since many nations operate nuclear submarines continuously, there can be little objection by governments to the

Russians deploying their nuclear power plants in this way or moving integral systems to their deployment sites by towing under the ocean. Apparently the factories for producing the reactors and for emplacement in the submarine-like containment exist now and probably are mostly idle. Rumors, which might be no more than that, are that more of these reactors were built than were placed in submarines so that the Alphabet Company perhaps need do little more than place an existing reactor in an old submarine hull and tow it to Archangel to begin its flow of income from power sales. Taking this altogether it would appear that the Russians have a new safe and environmentally sound reactor which is economically viable, which is probably deployable, and which requires little capital for deployment.

However the Russians seem to understand that in today's world it is necessary to advance not only the new reactor but also a plan for the full fuel cycle. Otherwise the reactor alone may not be accepted. Their plan therefore is to build a fissile material recycling facility at Archangel and to tow the reactors with their spent fuel in place back to Archangel. The plan is to use molten salt reprocessing to remove the fission product from the fuel and return the actinide to the reactor for its next cycle. They envision separations technology which never produces a pure stream of plutonium but leaves it always mixed with highly radioactive curium, americium and neptunium. Therefore no pure plutonium or other weapons material would be separated at any point in the fuel recycling. They also emphasize that the system produces no fission waste except the fission products and compare this processing to aqueous (PUREX) with the following statement. "One of the outrageous examples of the use of these (aqueous) technologies is the fuel regeneration method when reprocessing of each cubic meter of spent fuel produces 5000 m^3 of highly active waste and 17,000,000 m^3 of low active waste." The Russians seem to have adopted verbatim the separations plan for the Los Alamos Accelerator-Driven Transmutation Technology (ADTT). Of course this conceptual plan must be brought to practice and work in this area has already begun at the Chelyabinsk lab using internal discretionary funds. A more substantial effort on a molten salt loop will be initiated there soon using Swedish funds of about $ 0.75 M. Swedish funds in approximately the same amount also soon will be made available to the Kurchatov Laboratory, which has prior experience in molten salt technology, for demonstrating the different chemistry elements of a functioning fission products separations system.

The Archangel folks seem to welcome this new technology because of its promise to alleviate their acute electric power and space heating problem and to give a further much needed boost to a region which has snow eight months out of the year. Apparently the city already is home to a large naval industry and space launch facility and is the closest city to the remaining nuclear weapons test site on Russian territory (New Land Island). They seem to see a major industry in refurbishing the transportable reactors using the molten salt processing facilities and in preparing the waste for transport and disposal on New Land Island. Of course the funding supplied by Sweden for studing the separations technology for ADTT is nowhere near sufficient to develop the separations technology and to build the required facilities at Archangel. However, it would appear that a prime use of the funds generated by the sale of electric power by the Alphabet Company would go to the development and deployment of this separations technology.

It was also mentioned that the deployment of this new technology at Archangel would bring sufficient prosperity to allow clean-up of the radioactive contamination which is a serious problem for Archangel. New industry also would appear in St. Petersburg since the systems would be built and deployed by the St. Petersburg Marine Bureau of Machine Building "MALAHIT." The participation of several scientists from Chelyabinsk suggests probable interest there in the development of new fuel processing systems based on the molten salt technology for application to their existing waste inventory. The same can be said for Ukrainia and the Czech Republic which were well represented at the meeting.

Implementation

As is clearly evident, the Russian resources are severely constrained and it seems impossible for new ventures to proceed. Yet the Russians seemed to be confident that they had the resources to move ahead aggressively. Therefore at one of the social events I probed them as far as seemed prudent as to how resources could be found to bring this concept to practicality. I inquired about foreign investment of Drozdov who replied rather scornfully with this curious story. He said the Israelis offered to loan him funds for this project at 8 % interest. He said that he wrote them back saying that the Company was not interested. Then they wrote us back and reduced the interest rate to 3 %. He said they responded that they would have to *pay* the Alphabet Company interest before it would accept their investment funds. I responded that the Israelis have no money but U.S. money and I believe he interpreted this as meaning I didn't believe him. He bacame somewhat agitated and responded then in English, "We (Alphabet Company) are rich...rich!" Landa, who was present for translating responded emphatically, "Yes, we are rich...rich!" So apparently they are already capitalized for this venture.

The following is conjecture on my part . I have the impression that the Alphabet Company is backed at the highest levels of MINATOM which would like to see the technology commercialized. There may well be existing reactors which were never placed in subs (according to some comments at the meeting) and there are certainly many old submarine hulls. Therefore it would take little money for the placement of the reactors in the hulls and towing them to Archangel for deployment. This funding probably could be made available by the Russian government but perhaps also by private investors. The Archangel population would almost certainly welcome them in view of their acute power shortage and the rest of Russia may care little for what goes on at this remote nuclear naval base. Therefore there would appear to be little financial or political problem with near-term initial deployment. The power sales would generate revenue for paying off probably a small debt and provide funds for further inexpensive deployments. The resulting geometric growth in revenue would also allow the separations chemistry to proceed aggressively with the possibility of deployment of these facilities at Archangel in 7-10 years.

In the meantime the success in Archangel might allow the deployment outside of Russia. The nations mentioned for this off the meeting floor included Egypt, Palestine, Cyprus, and Greece. None of these nations has a nuclear technology base, and none need be developed to reap the benefits of nuclear power since the Russians would bring the power station by sea and tow it away at end of life after replacing it with another. Success with these smaller nations where power is limited and the cost is high might make it possible to move on to wealthier nations such as Singapore, the Philippines, and Hong Kong. Since a large fraction of the world's population lives within several hundred miles of the seacoast, the potential market for these systems is very large. The fission product waste from these systems all ends up under New Land Island in the Arctic, which is perhaps a good place for it.

A problem with all fast reactors is the high inventory of fissile material which they require. It is possible to estimate fairly accurately what the fissile material inventory would be for a fast reactor running with an initial load of 20 % fissile material and cooled by liquid lead-bismuth with a core life of 10-15 years. I believe that the number might turn out to be about 2.5 tons of fissile material for a 0.1 GWe system. Since the world's nuclear power generation capacity now is about 325 GWe, it would take over 3000 of the Russian systems to replace the present power generation capacity. To launch them would take 7500 tons of fissile material. The Russian inventory of fissile material may be about 100 tons of weapons plutonium, 300 tons of commercial plutonium, and 2000 tons of HEU. Therefore the Russian inventory would allow the replacement of about 1/3 of the world's existing nuclear power capacity. If the world nuclear power generating capacity were to grow considerably, this would mean that the Russians would not have the fissile resources to supply more than a small fraction of the world's nuclear electric power. Nevertheless the annual income from the sale of this portion of the world's nuclear power capacity would be about $40 billion.

Since these facilities are under control of the Russians, there is no possibility for surreptitious removal of fissile material for nuclear weapons purposes by the host nation. However, the large inventory does carry the risk of abrogation in which the host nation might lay claim to a reactor and remove the plutonium for nuclear weapons purposes. One reactor might provide an inventory of several hundred nuclear weapons. This scenario is rather unlikely however for deployment at sea, since it might be relatively simple for the Russian navy perhaps with the aid of other navies to prevent successful access to the reactor once it was threatened.

These reactors would be operated with a conversion ratio of unity so that they would contain as much fissile material at the end of operation as at the beginning. Of course they could be operated as breeders as well, but the long intervals between fuel replenishment argues against this. If at each fuel cycle of 10-15 years the plutonium had grown by 10 %, it would take roughly eight cycles or about 100 years for one system to spawn enough plutonium to start a daughter system. Therefore breeding would have little impact on the overall economics or deployment rate of the systems and there would be no economic incentive to breed with these systems.

Impact on plutonium and HEU disposition

We see that the Russians now have enough fissile material to fuel about 1000 of these systems. If 30 of these systems were built per year, the deployment would be completed in about 30 years. In view of this early date, there would appear to be little interest in any of the plutonium or HEU disposal programs which the U.S. has been trying to push onto the Russians.

As long as the Russian's only option for the use of this plutonium was in the liquid-sodium-cooled reactors, the U.S. could make a good case for destruction of the fissile material because of the safety of these systems and their breeding potential. However these heavy-metal-cooled systems do not suffer from the problems of the sodium fast breeder and breeding is not of interest for the deployment planned. Furthermore since the Russians retain ownership of the plutonium or other fissile material, no market for the plutonium is created. Finally the molten salt separations process does not create a pure weapons material stream which the aqueous technology does create and the waste is limited to the fission product stream.

Conclusion

A newly developed and demonstrated reactor technology possessed only by the Russians has appeared which seems to provide significantly greater safety than the conventional sodium-cooled fast reactor design. It appears to be deployable with modest resources and with little risk of opposition by other nations. It is able to consume any fissile material and can be deployed with little risk of nuclear diversion or proliferation treaty abrogation. The proposed deployment appears to eliminate practical operation as a breeder. Substantial deployment of this system will require all of the fissile material now existing in Russia. There is little likelihood therefore that Russia will respond to U.S. pressure to follow the paths advocated by the U.S. National Academy of Sciences of partial destruction or disposition with little benefit. Clearly the Russian fissile material has a high positive value for use in deploying this technology in spite of NAS and DOE assertions that the value of weapons plutonium is strongly negative.

White Land Notes
Charles D. Bowman
Los Alamos National Laboratory
Prepared 2/22/96

These notes were taken during the "White Land" meeting and are intended to supplement the report entitled, *"White Land"....New Russian Closed Cycle Nuclear Technology for Global Deployment.* They give more detail on various speakers presentations and should be considered as supplemental to the above document.

Dr. S. Subbotin, Kurchatov Institute

Subbotin gave the talk introductory to the technical discussions. Dr. Victor Orlov, designer of the lead-cooled reactor, chaired this opening session of the meeting. Subbotin began by saying that there should be no geographical restriction of energy and that nuclear energy should be available to everybody. (While the most advantageous deployment of White Land seems to me to be by sea, the plan is to carry these reacters on rivers or overland as well.) The strategy is to deploy for commercial use the lead-bismuth cooled fast spectrum reactors developed for nuclear submarine propulsion. Dry processing will be used for spent fuel and molten salt reactors (I believe they meant accelerator-driven systems) would be used as burners for long-lived waste. The benefits of this new reactor technology are listed as ultimately safe, flexible, transportable, commercially acceptable, mature technology and ready for production. The white land of the Russian Arctic would be used as the sites for reprocessing and storage of the waste remnant.

Prof. L. Menshikov, Kurchatov Institute

Menshikov is attached to the Kurchatov institute but is a native of Archangel and spends much of his time there now. He is a theorist in muon-catalyzed fusion. The purpose of his talk was to show the superiority of a reactor system backed up by a waste destruction system as compared to the possible performance of magnetic fusion system. He began by comparing the volume of the power producing portion of fusion and fission systems arguing that the price of high-tech equipment of this type is proportional to the volume. He compared the volume of 3000-MWth systems and explained that the volume of the fission reactor was 200 m^3 compared to the volume of the fusion donut of 5000 m^3. He concluded that the capital investment for fusion is much larger than for fission. He says that the Vienna based IIASA Organization first pointed out that the fusion systems will leave behinds more radioactive waste than a fission system with waste burning. He explained that if the minor actinides and I and Tc were destroyed (he says it takes 4 % of the reactor energy to do this using an accelerator), that the radioactive remnant from fission and fusion are the same. Fission is much better than fusion if ^{137}Cs and ^{90}Sr are destroyed, but this would take 30 % of the accelerator power. The second conclusion is that fusion is not more pure than fission in terms of radioactivity.

He went on to explain that there is as much energy available from fission processes as from fusion but I didn't record his whole argument. He dismissed fusion/fission hybrid systems which use fusion neutrons to produce ^{239}Pu from ^{238}U by arguing that fission reactors (e.g., converters with $\beta \approx 1$) can produce their own plutonium and so that this is not a problem for reactors. He quotes the U + Th resource as greater than 20 X 10^6 tons at a price less than \$250/kg. Therefore there is no economic or other benefit from a hybrid system. He further explained that the fundamental technical problem with fusion are the first wall and strong energy losses in the plasma. The first wall is a serious problem unlikely to be solved but the radiative losses are even more important. He argues that the radiative emission is always calculated to be much lower than actually observed. The explanation he says is that all calculations are based on single electron emission. However he argues that the electrons in the plasma do not radiate independently but emit radiation collectively (or coherently). When collective radiative emission is included, it can be shown that the radiation losses are too high to allow fusion without net power input.

There was much discussion at the end of the talk and the chairman of the discussion Orlov closed it by remarking that while some of Menshikov's points were perhaps contestable, it was difficult to see how fusion offered significant advantage over fusion on any of the main concerns of nuclear power production.

Dr. Vladimir I. Chitaykin, Assistant to the Director, Obninsk

Chitaykin was formerly with Chelyabinsk-70, but is now at Obninsk with IPPE. He is a good friend of Grebyonkin of Chelyabinsk-70, who is our chief contact for ISTC there. He asked why the U.S. is so focused on the safety of weapons plutonium when the real problem for proliferation, terrorism, etc. is with commercial plutonium. He argued that building a bomb with commercial plutonium is much easier since the neutrons are already supplied by spontaneous fission and the timing of the initial neutron burst is unimportant. He stated that the yield might be uncertain between 1 and 20 kilotons put for all practical purposes there is little difference. Similar conclusion have been reported recently by Carson Mark in "Reactor-Grade Plutonium's Explosive Properties,' Nuclear Control Institute (1990). Therefore taking the weapons plutonium to the spent fuel standard makes it more dangerous rather than less so . He says that even though planners in the U.S. and elsewhere might not recognize this, any terrorist organization seriously contemplating the possibility of use of plutonium will prefer commercial plutonium to weapons plutonium. I report this because it seems to represent a sound argument and thoroughly defendable position and a hardening of the Russian stance against weapons plutonium destruction or disposal without maximum benefit.

Prof. G. Toshinsky, Institute of Physics and Power Engineering, Obninsk. Russia

This was the main description of the White Land technology. He began by describing an effort in another country to place a metal-cooled reactor in a submarine. This first attempt failed because of numerous fires arising from leakage of sodium. Next a liquid metal cooled system burning ^{233}U from the thorium-uranium cycle was attempted. The main problem with Pb or Pb-Bi was to deal with corrosion and to keep a solid mass of floating material from clogging the circulation system. The project attempted to address the corrosion problem by establishing a thin layer of $ZrNO_3$ on the metal surfaces. A role for magnesium at the 0.005 % level was described for limiting the oxygen content of the liquid metal, and this required operation at the temperature of 600 °C. Leakage of water from the steam generator into the liquid metal was not good because the water reacted with the magnesium and hydrogen would be formed which would destroy the $ZrNO_3$ coating. The submarine power plant had to operate under the condition of a water leak into the heat exchanger since small leaks of this type are difficult to avoid entirely and the submarine could not be vulnerable to loss by this means. Also the $ZrNO_3$ layer could be damaged in assembly of the reactor components and means to repair it were not available. Therefore this effort to place a heavy-metal-cooled reactor into a submarine failed.

In Russia a different approach was taken involving an iron-chromium working material. For self healing and cure it was necessary to keep a certain percentage of dissolved oxygen in the lead-bismuth. If the oxygen content is too low, the heavy metal becomes aggressively corrosive destroying the fuel assemblies. If there is too much oxygen, lead oxide forms and produces a residue which causes clogging. The solution of this problem didn't come all at once. It took 15-20 years of hard work by several institutes, but a very dependable means of controlling the dissolved oxygen has been developed. Oxygen in free and compound form were problems. In order to keep oxygen at some level, it was necessary to supply oxygen inside and to determine the high and low limits for normal function. During maintenance, oxygen from the air couldn't be allowed into the liquid metal system.

These reactors have been used very long and successfully in nuclear submarines. Assuring r iation safety to the submarine crew in case of a coolant leak was required. This was associated with the alpha decay from ^{210}Po. The safe means for maintenance and repair have been worked out. What helped a lot was the 10^{-8} level of polonium in the coolant system and also that Pb-Po eutectic reduces the vapor pressure to a significant degree. The analysis of the health condition of the Russian sailors showed that some had polonium in their bodies, but the amount was lower than required by health standards. This was in the beginning when safe methods of repair had not been developed. In the end, when repair work on a sub was required, a respirator on the face provided adequate protection. Objects floating in the liquid metal could be lifted out with a strainer. Later special suits were developed for the maintenance.

One of the attractive features of the system was its very low vapor pressure with a high boiling point of 1000 °C. When/if a steam pipe broke and steam went into the first (liquid metal) circuit, it was readily removed from the heavy metal, so that the reactor could continue to operate even in the presence of small leaks in the steam generator system. The system does not release waste when there is a Pb-Bi leak because the Pb-Bi solidifies and confines the radioactivity. The system is therefore superior in this regard to LWR sub power systems.

He mentioned that seven or eight of these subs were built according to reports published in Norway. The total time of operation of these lead-bismuth cooled reactors is 80 reactor-years. The tremendous speed made possible by the use of these compact power plants placed them in the Guinness book of records. The research on this technology was performed at Obninsk, the reactors were developed at Hydropress and the reactors and subs were built at St. Petersburg. After the Chernobyl experience, analysis of the safety of various types of nuclear reactors drew attention to the extreme safety of this type of reactor.

(I'm afraid I could not keep up with the arguments in this paragraph and am just reporting what I had in my notes.) There are two approaches to safety today. People use probability figures multiplied together. This approach addresses the consequences of the accidents but not the reason for the accidents. But we don't know when an accident will happen. Consider for example a goal oriented event such as a terrorist attack and then all safety system layers can be destroyed. Can we reach the required level of safety without piling on layer upon layer of safety? It has been suggested that in the next century, the harnessing of fission should be different from that pursued in this century. Weinburg has pursued this theme in the U.S. and Orlov in Russia. We should remove the reason for the accident so that we do not have to deal with consequences.

If we choose Pb or Pb-Bi cooled systems, then we have a system with minimal amount as stored energy. By contrast, in a water reactor, the energy content is high because the pressure is high. If sodium is used, there is a large amount of chemical energy available which will assuredly be released in the case of leakage.

The Pb-Bi reactors are planned to be offered in sizes of 1, 6 , 50 and up to 200-MWe systems. They may be floating or stationary units. The 1-MWe systems can be transported in a few sections by helicopter. Owing to their extreme safety, they can be placed in cities to provide both electricity and heat, which cannot be transported long distances.

Assuring the safety of nuclear power plants is important. Another safety issue is that for the entire fuel cycle. A difficulty with the present approach to reprocessing is the possibility of plutonium diversion. So the U.S. has stopped the recycling of nuclear materials and work on fast reactors which can breed plutonium has been stopped. However this policy can exist only for a time defended by the availability of cheap uranium.

He then went on to describe a modification of LWRs to lead-bismuth cooled systems which allowed them to become breeders. They would then start with 20 % enriched uranium and with recycling could burn 20 % of the total uranium rather then the 0.5 % which present systems burn. He says it would take 8 years to convert the existing Russian 440 MWe VVERs to Pb-Bi cooling. I am not familiar with the details and the burden such a system might place on repository storage, but he says its documented in the 1958 Geneva Conferences Proceedings on the Peaceful Uses of Atomic Energy.

Prusakov, Kurchatov Institute

He began with the chemistry of a molten salt system core, so this talk was not directly relevant to the White Land program. However it was indirectly significant since the White Land program includes molten salt reprocessing for the lead-bismuth reactors spent fuel. He says that maintaining the redox potential in the core is important to keep corrosivity in the correct range. It is also important to know how noble and semi-noble metals behave in the system as they might become volatile. The disposition of Kr and Xe is simpler. He says that a lot of different chemistries have been invented which might be useful: electrochemistry, precipitation of oxides, and bismuth metal separations. He says that the old work in the U. S. primarily at Oak Ridge is good correct work as verified by less in-depth studies in Russia. He has worked with the bismuth separation process and sees benefit in using centrifugation for separation of the actinides and lanthanides He was not referring to a centrifugal contactor but to molecular centrifugation.

He was strongly upbeat on the promise of dry chemistry and seemed excited about the possibility to restart work on molten salt separations at Kurchatov. He explained that after Chernobyl all work in this area was stopped and all of the equipment was disassembled and sent to the Czech Republic.

(The following was gathered in subsequent private conversation.) He has worked with the Kiev lab on molten salt chemistry and believes them to be highly knowledgeable. (Los Alamos ADTT staff has taken steps to try to get Ukrainian ISTC funds allocated from Sweden into this lab.) He described the different states of plutonium saying that PuF_3 and PuF_4 are both stable and that he has made PuF_6 but that it is very unstable. This relative instability can be used for separation of Pu and U in a single step operation. Therefore he says it is possible to remove uranium and leave fission product and the actinides behind (which is what we have proposed for ADTT front-end separations). He proposes to clean up the rest using reductive extraction and electrochemistry and to apply a centrifuge to the separation of actinides and lanthanides as desolved species in bismuth. He is concerned about the disposition of some of the fission products worrying that some of them depositing on a surface could burn the walls because of decay heat. I don't understand this.

Dr. I. Peka, Nuclear Research Institute, Rez, Czech Republic

Dr I Peka has received the equipment from Kurchatov and it still remains in storage. He explained that he has worked with Kurchatov for many years. He described the Oak

Ridge work using the bismuth with lithium for separations and described front ends and back-end separations which looked very similar to recent Los Alamos plans and which seemed to be influenced by Los Alamos to a significant degree. He mentioned the options of both molecular centrifugation or the Oak Ridge system for lanthanide-actinide separations. He showed a picture of a flame fluorinator which had been built and operated at Rez and the nearby condenser for condensing zirconium or uranium fluoride. He mentioned that they had capability to separate U and Pu based on the instability of PuF_6 and the full understanding of the Properties of PuF_3 and PuF_4. By absorption methods they have capability to purify all of the gases and the full system has the capability to process 3 kg of spent fuel per hour.

He showed a picture of the system in a glove box with uranium being burned in fluorine. The window through which the picture was taken was made of sapphire which is not affected by heat or fluorine gas. He then outlined quickly a chemistry program which I was not able to follow well. He spoke of the optimization of the dissolution of fission products in fluoride salts with HF. He mentioned the need to build up six basic designs for the reprocessing and the need to develop technology for returning the LiF and BeF2 to the blanket because of the expense of these materials. And he mentioned the need to develop a system for removing UF_6.

In summary, the Czechs are highly knowledgeable and have significant practical experience in dry fluoride-based chemistry. I have the impression that the issues for ADTT or for White Land have not been thought through completely or else I was getting the too mixed up in interpreting his presentation. Peka is near retirement and an effective program in the Czech Republic would require the participation of younger people.

Dr. A. Lecocq, EURIWA, Paris, France

Dr. Lecocq has been the primary advocate for dry processing in France which has focused most of its work on aqueous processing. He began his molten salt work in the seventies. He complained that everybody designs reactors but chemists and that this is the root of the problems with nuclear technology. He said that the work at Oak Ridge was very good and important and waved a list of seven pages of references to on ORNL molten salt work. He called the Molten Salt Reactor at Oak Ridge the chemists' reactor. He mentioned the many advantages of a molten salt reactor and the advantages of the thorium cycle including reduction of the minor actinide production. The French evaluated the U.S. work and found it to be very attractive from a technical and performance perspective. The French continued this work until 1983 but stopped it then because of competition from the FBR Superphenix. He retired at that time. He has never agreed with the aqueous reprocessing route and has not been so popular in French nuclear power programs for this reason. He has continued as an advocate for molten salt technology but probably would not be active in any new French molten salt experimental activity. He recommends Alvin Weinberg's new book "The First Nuclear Era" for those contemplating a new nuclear power future and who want to get it right the second time around.

Prof. A Karelin, Radium Institute, St. Petersburg, Russia

He prefers fluoride methods of reprocessing. He described mainly his concepts for deployment of the reprocessing systems advocating underground location at a depth of 50 meters. He called for cooperative effort in order to get to demonstration facilities as soon as possible.

Prof. H. Sekimoto, Tokyo Institute of Technology

He gave a short poorly translated and rather highly technical talk on reactor operating properties, and burn-up dynamics. I have the impression that he is a good scientist with a strong interest in advanced reactors and new fuel cycles and that he will probably play a key role in the Japanese nuclear power future.

Dr. Henri Conde, Uppsala, Sweden

The Los Alamos ADTT office has been in close contact with Dr. Conde for many years and he is a strong advocate for ADTT in Europe. The purpose of his paper was to describe the Swedish underground storage system for commercial spent fuel. He says that their waste will go 500 meters underground in copper canisters. By 2010 the Swedes will have 8000 tons of spent fuel. The Swedes operate 12 nuclear power reactors. Their final budget for waste disposition is $ 6.5 billion. This funds are provided by a charge of 0.02 crowns per kilowatt hour. The fuel will be transported to the site by special ship. The Swedes are required by law to keep track of alternative developments for spent fuel disposition and his role has been to help promote the ADTT-like efforts in Sweden and the rest of Europe.

Dr. Y. Davidov, "Atomenergoproekt" Moscow

His task was about the implementation of porous materials for the new molten salt reprocessing technology. He mentioned that a most obvious use for porous materials was in the filtering of aerosols, but he said often several processes can be combined into one. As examples he cited the combination of electrochemistry and centrifugation using highly porous materials as the electrodes. He also spoke of thin-walled chromatography. He mentioned that porous materials can be made from metals, ceramics, and plastics. He spoke of the use of Teflon in this context. When I asked him if he could make these porous materials of Be, he responded that the most common means of of producing them was using powder metallurgy which was not so successful with Be or Al. The technology he described appeared to offer promise for enhances separations in molten salt systems.

Dr. L. Shestakov, Pomorsky International University, Archangel

He described the acute energy shortage of the region owing to the cold and the long winters. Yet Archangel is a key technical city in Russia with extensive submarine facilities, space launch facilities, and New Land Island, which is presently their nuclear test site and proposed future site for the White Land remnant waste storage.

Dr. A. Drozdov, Alphabet Company, Moscow

He began by arguing that the objective should be not to focus on the safety of an existing reactor but instead to promote safety of a world nuclear energy system. He believes that the White Land concept satisfies the world-wide perspective. He spoke of the concept of moving the whole reactor to the deployment site and back so that nothing is done at the power generation site except production of power. He says that a market exists for such devices and that a new power plant can be produced in 2.5 years from time of order. The philosophy is to build something new now which can be deployed immediately and which can generate revenue from power sales and to "grow" the company from there. Archangel is obviously the first place where such a plant would be located. He closed by arguing that one should forget improvement of existing deployed reactor types for nuclear power production and move on to the entirely new systems. This seems to be consistent with views of Hafele, Weinberg, etc.

Dr. Victor Orlov, Kurchatov Institute, Moscow

Orlov is credited with the development of the lead-bismuth cooled fast reactor and was prominent throughout the meeting. He conducted a round table after the end of the meeting and spoke for the first time there. He began by saying that the deployment of nuclear energy should grow by a factor of ten and that the rate of use of uranium should decrease by a factor of ten at the same time. This is possible using the lead-cooled fast reactor. He says that the breeding ratio should be exactly one so that the system does not produce additional plutonium. The spent fuel processing should extract only fission product. The system should return to the earth no more radioactivity to the earth than was taken out in the uranium mining. To accomplish this all actinides should be burned in fast reactors. The Sr and Cs should be used as stable sources of heat. The long-lived fission products should be burned as well and the remnant fission products should be stored for about 200 years to reduce the radioactivity by about a factor of 100. To reach these objectives no more than 10^{-3} to 10^{-4} of the actinides should be present in the fission product remnant.