US/RUSSIAN LABORATORY COOPERATION IN SCIENCE AND TECHNOLOGY UNDER A NEW AGREEMENT ON NUCLEAR AND ENERGY RELATED R&D

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On Sept 16, 2013, the US Secretary of Energy and the Director General of ROSATOM signed a new agreement on “Cooperation in Nuclear- and Energy-Related Scientific Research and Development” creating a new accord between the governments of the United States and the Russian Federation supporting scientific exchange in fundamental and applied science, global security and energy related research. For the US National Nuclear Security Administration Laboratories (LANL, LLNL and SNL) and for the ROSATOM RFNCs (VNIIEF, VNIITF and VNIIA) the new agreement paves the way for new forms of cooperation, but requires some adjustments to old patterns to take advantage of these new opportunities.

Starting with discussions at the XV Khariton Readings in March 2013 both US and Russian Laboratories have formulated theoretical, computational and experimental proposals for cooperative projects ranging in scale from small (bench-top) to relatively ambitious; and with topics ranging from computer systems and architecture - to computational physics, - basic properties of materials - and to applications of high explosive driven pulse power generators.

Formal cooperation in unclassified, non-sensitive science and technology (S&T) between US and ROSATOM laboratories specifically in disciplines related to nuclear explosives science began with a first exchange of technical experts in January 1992. The opportunity for these timely discussions grew out of relationships formed in open scientific channels (journals and conferences) during the Cold War. These discussion among technical experts, provided the opportunity to extend invitations for exchange visits by the Laboratory Directors to both Russian and US Labs in February and March 1992. The first joint, formal, S&T efforts (cutting-edge experiments conducted by joint US/Russian research teams, first in Sarov, and then in Los Alamos) occurred in the fall of 1993. These early efforts were followed, in short order, by expanded exchanges in plutonium science and joint S&T projects in pulsed power technology and applications, and within a few years by joint projects in material science experiments and modeling More recently joint projects in computational physics and computer science have been added.

In June 2011 directors of six laboratories meeting in LLNL identified four high level areas of cooperation including: 1) the traditional S&T cooperations in areas supporting the labs’ main nuclear security missions; 2) counter-proliferation and counter terrorism topics; 3) civilian nuclear power and 4) broader topics of energy and environmental. In October 2011, US/Russian technical experts meeting in Barcelona explored an expanded list of S&T topics, ultimately identifying a family of ten, relatively detailed, areas of continued or expanded scientific cooperation growing from the Laboratory’s and RFNC’s core national security missions. In June 2012 the Directors, again, met, in Sarov, to evaluate progress and to further articulate directions for future research. The new Agreement was signed in September 2013, and the Lab directors met again at the 25th Anniversary celebration of the Joint Verification Experiments in Las Vegas, Nevada, discussing proposals for future cooperation.

Unclassified, non-sensitive technical projects, conducted jointly by the NNSA Laboratories and the Russian Federal Nuclear Centers provide unique scientific insights in the fundamental physics areas that underpin the principle nuclear security missions of both NNSA and the ROSATOM. In this paper, we will summarize of the important features of the new Agreement, discuss some of the proposals currently under consideration and discuss the potential for cooperation over the next few years.

Introduction

In the spring of 2014 international relations were strained and it is not the first time in the history of US/Russian cooperation, since the end of the Cold War, during which international tensions have brought into question our ability to continue to cooperate as scientists. Timing for the Khariton Conference was such that the US delegation was not able to travel to

Sarov in April 2014 and the tri-lab US team was disappointed by the circumstances. However, the US team continues to hope that the issues that have precluded their travel will be resolved soon and that we can quickly return to the normal scientific exchanges that we have enjoyed in the past. With that hope in mind, this paper discusses the prospects for US/Russian laboratory and institute level cooperation in 2014 and beyond.

Our discussion focuses specifically on a set of projects, identified by our US Laboratories and approved by NNSA for discussion and if common interest emerges -- and resources can be found -- for a future start of work. Further, as we have done in the past we discuss a few thoughts about the broader opportunities for cooperation, -- topics that extend beyond those already formulated into specific projects.

From a Los Alamos perspective, working with the RFNC's at Sarov, Snezhinsk and with the RAS through Sarov Labs, we have, successfully, completed the research, analysis, and reporting that was planned in all the research projects for which we signed contracts under our former Lab-to-Lab paradigm. That work was most rewarding, stimulating, in many cases ground-breaking. It was valuable to the US, and, in the opinion of those involved, it was valuable to Russia as well. Because of vigorous joint publishing efforts in meetings like the Khariton series, and in the open literature of both nations, that work has been valuable to the scientific community at large. As just one example, an account of some new material damage experiments, conducted with pulsed power drivers, jointly designed by the US and Russian teams, numerically simulated by both teams, and executed at Sarov with US supplied diagnostics, has recently appeared in both the Russian literature in *Doklady Akademii Nauk* (DAN) and in the English scientific literature in the Journal of Applied Physics. In another example, Los Alamos, Livermore and VNIIEF continue to (independently for the moment) consider technical issues associated with the ALT-3 experiment initiated under the Lab-to-Lab paradigm.

Agreement on Cooperation in Nuclear- and Energy Related Research and Development

After several years of negotiation, the US and Russian governments have completed an important, new, government-level agreement on research, development, science and technology exchanges that was signed by Mr. Kirienko (ROSATOM) and Dr. Moniz (US_DOE) in Vienna in September 2013. While the new agreement shifts the mechanism for cooperation away from US funded contracts to a more peer-to-peer model, both the US and Russian governments are soliciting proposals for specific research projects, and both NNSA and ROSATOM are preparing appropriate implementation procedures to exchange, review and authorize work. If agreements on common interest and on the value of the work on specific projects to both sides can be reached, and if resources, including funding, can be identified on each side, work on these projects can be planned in the future.

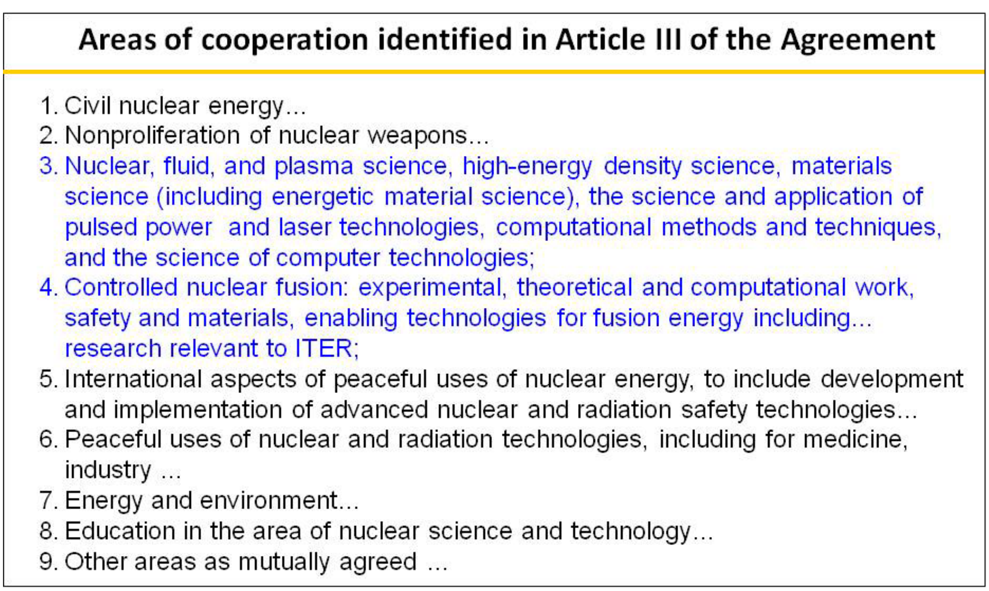

Fig. 1. Eight areas of cooperation identified by the Moniz/Kirientko agreement of Sept 2013

Figure 2. ROSATOM research facilities in Russia and NNSA facilities in the US that are authorized to conduct cooperative projects

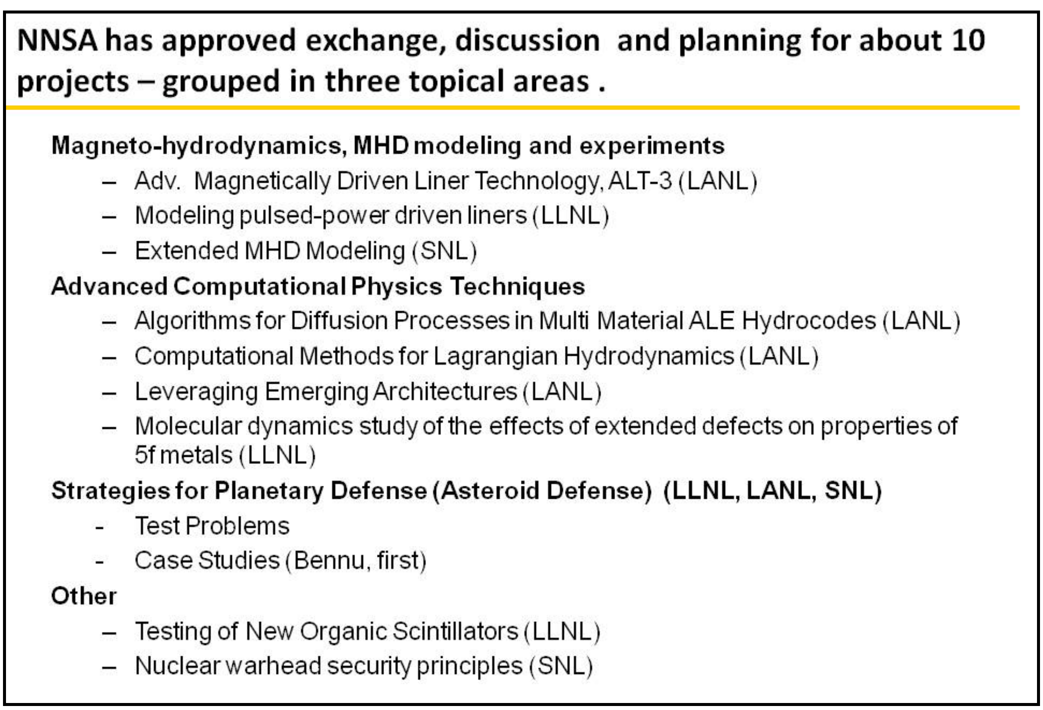

Figure 3. Ten specific proposals from the US-NNSA fall into three large topical groups with multi-laboratory interest in each

The Agreement identifies 8 broad areas of cooperation, listed in Figure #1, plus an acknowledgement that other areas can be added by mutual agreement. Of those eight areas, two are particularly interesting to this audience: first, is number 3 the area of nuclear, fluid and plasma science along with material science; and second is number 4 the area of controlled nuclear fusion. The topics of this Khariton Readings, generally fall into these two areas, and so, if there is mutual interest, almost any topic on the agenda of this conference could be an opportunity for future cooperation.

Item 8 on the list in Figure 1 is the general area of education and training for the next generation of researchers in the areas of the main nuclear security mission of our respective institutions-- and I think this topic is as important to the Russian Federal Nuclear Centers as it is to the NNSA Labs.

The Agreement names 14 Institutes and Centers in Russia and 15 Laboratories in the US that are authorized to participate in joint efforts including LANL, LLNL and Sandia; Sarov, Snezhinsk and VNIIA. The complete list of institutions is shown in Figure 2 At each of these institutions the Agreement also names a number of specific facilities that could (under the right circumstances and with the appropriate agreements) be employed for joint work such as the X-Ray complex RGK-B and the criticality facility FKBN-2M in Sarov along with eight other facilities at VNIIEF. Similarly the Agreement names DARHT, the proton radiographic facility at LANSCE, and the Trident Laser among a list of 25 facilities at LANL. Similar lists of facilities that, with the proper planning and authorization, can be used for cooperative work are named for each of the US and Russian institutions.

An Initial Group of Projects for Exchange, Discussion and Planning

As a first step in this process the US National Nuclear Security Administration has approve 10 specific projects for exchange, discussion and planning. If discussion leads to agreement, NNSA and the US Laboratories are willing for work to begin on these projects in the future. While one of our US Laboratories is designated "lead" for each project -- most projects actually involve more than one US Laboratory. These ten specific proposals fall nicely into three larger topical groups (plus a few additional topics) where each topical group has multi-Laboratory participation. All three US labs have interest in pulse power driven experiments, and the accompanying MHD models, as well as the topic of magneto-hydrodynamics in general. Our continuing interest in the ALT-3 experiment can form the launching-pad for, but not necessarily the entirety of, a broad, bi-lateral, effort in this area.

The second area of interest is that of advanced computational physics techniques including Lagrangian, Eulerian and ALE techniques for condensed matter and plasmas; topics related to computer hardware architectures; and a continuation of work in atomistic (molecular dynamics) simulations. Discussion all of these topics began under the Lab-to-Lab paradigm.

The topic of planetary asteroid defense continues to be of interest. The meeting in Snezhinsk in October 2013 lead to agreements to work on a select set of test problems, and even a focus on modeling using one (or a few) specific, well studied, asteroids. Another meeting, in Livermore, is being planned on this topic, although the date is not set. In the next part of the talk, I'd like to comment very briefly on each of the projects that NNSA is offering for Russian consideration grouping them into these three topical areas.

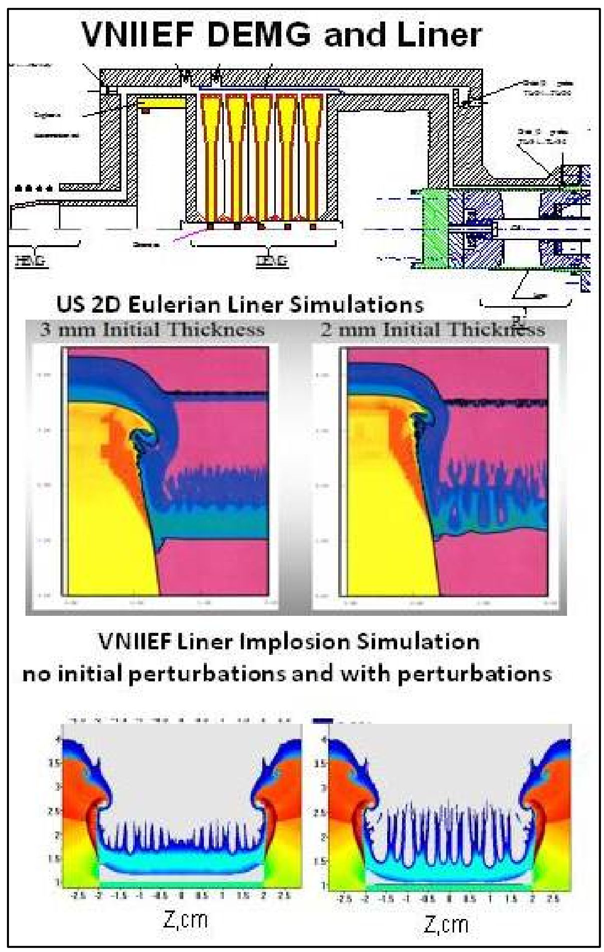

Fig. 4. The ALT-3 experiment engages several Labs and RFNCs

Cooperation in MHD physics, modeling and pulsed power applications is among our longest running cooperations, and because the ALT-3 experiment has been in development for the last several years under the lab-to-lab paradigm, it is somewhat more mature. The objective of the experiment is to employ a high precision 20-km/second impactor to explore the feasibility of high-precision, terra-paschal, EOS measurements. The experiment would use a VNIIEF designed Disk Explosive Magnetic Generator to deliver the 60-70 MA needed to power a cylindrical liner implosion. The US has fabricated the high precision experimental assembly, and would provide the sophisticated diagnostics needed to make the EOS measurements. Both VNIIEF and LANL have performed MHD calculations of magnetically imploded liner performance at parameters needed for this experiment. An interesting and challenging aspect of this experiment is the long term possibility of bringing the experiment, including the DEMG, to the US to perform a series of similar experiments in the future. There are three projects within the scope of the topic of pulsed power applications and magneto-hydrodynamics, The first project is summarized in Figure 5.

In this first project, we anticipate continuing work on the ALT-3 project, developing a pulsed power driven imploding liner platform for EOS and condensed matter hydrodynamics experiments. There is an existing US/Russian team that has been developing this experiment over the last 5 or more years. The expected outcome is publishable experimental data in a regime of liner implosion velocity leading to material conditions that have not been accessible. The US team is devoting about three-quarters of an full time equivalent (FTE) to this effort this year, primarily in fabricating the precision experimental assembly. An FTE is a measure of effort equal to one person working for one full year.

Livermore National Laboratory proposes to add LLNL simulations (Figure 6) to compare with those of VNIIEF and LANL. Aaron Miles has performed some simulations using Lawrence Livermore Laboratory's MHD simulation tools to further explore the role that hydrodynamic instabilities play in limiting imploding liner performance. Since very high precision implosions -- at least very high precision over that part of the liner surface that drives one of the EOS experiments -- is essential for a successful measurement, improving our insight into all aspects of imploding liner performance is essential. From Livermore, Aaron is joining the LANL team working with Anatoli Buyko and Sergey Garanin in the modeling effort. An important outcome of this effort will be the comparison of LLNL, LANL and VNIIEF codes with the new experimental results.

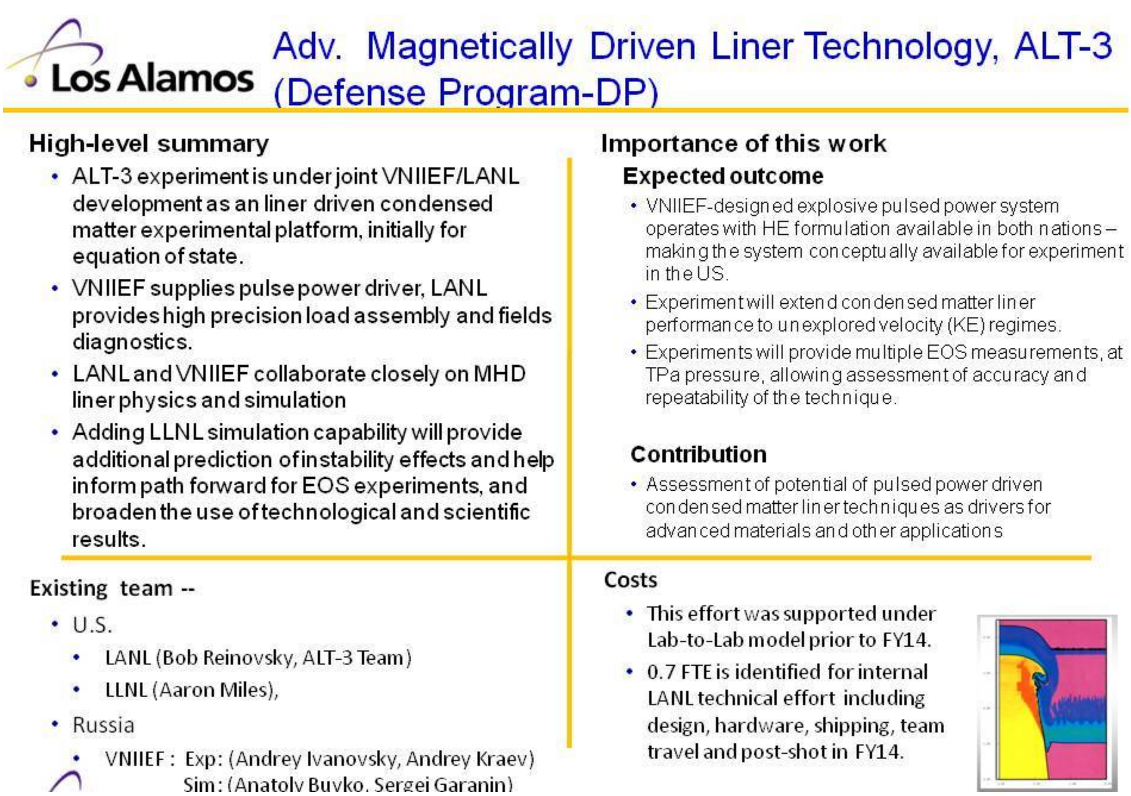

Fig. 5. Proposal for ALT-3 experiment

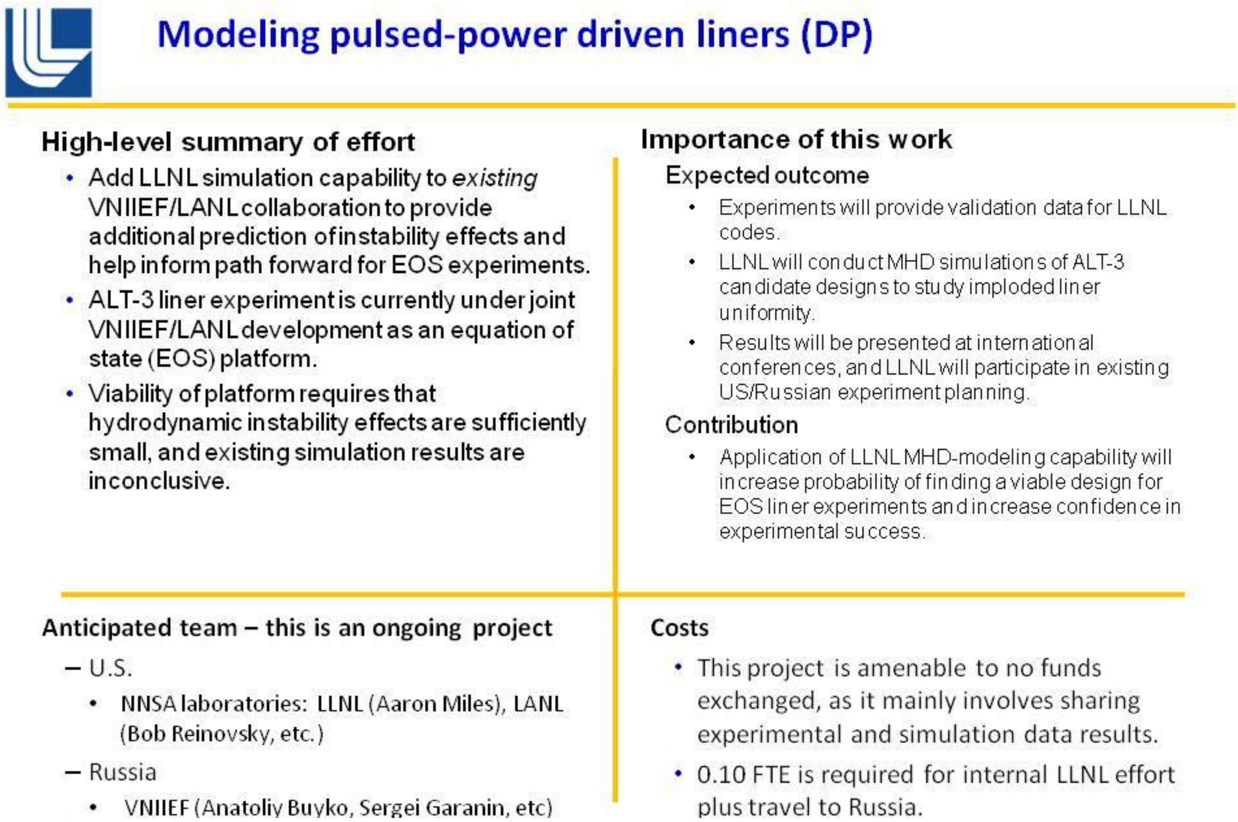

Fig. 6. Proposal for modeling of the physics of pulsed power driven liners

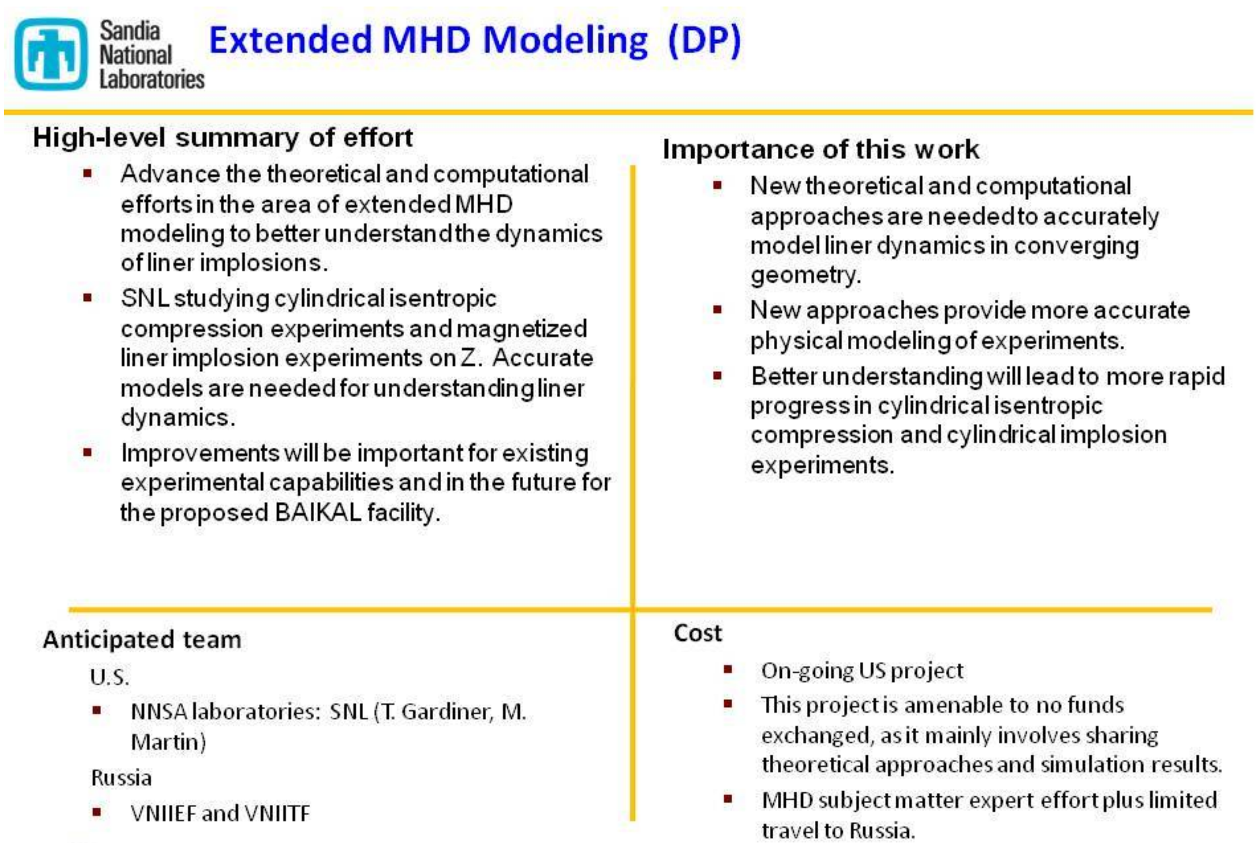

Fig. 7. Other applications of magnetic driven implosions employ advanced MHD modeling

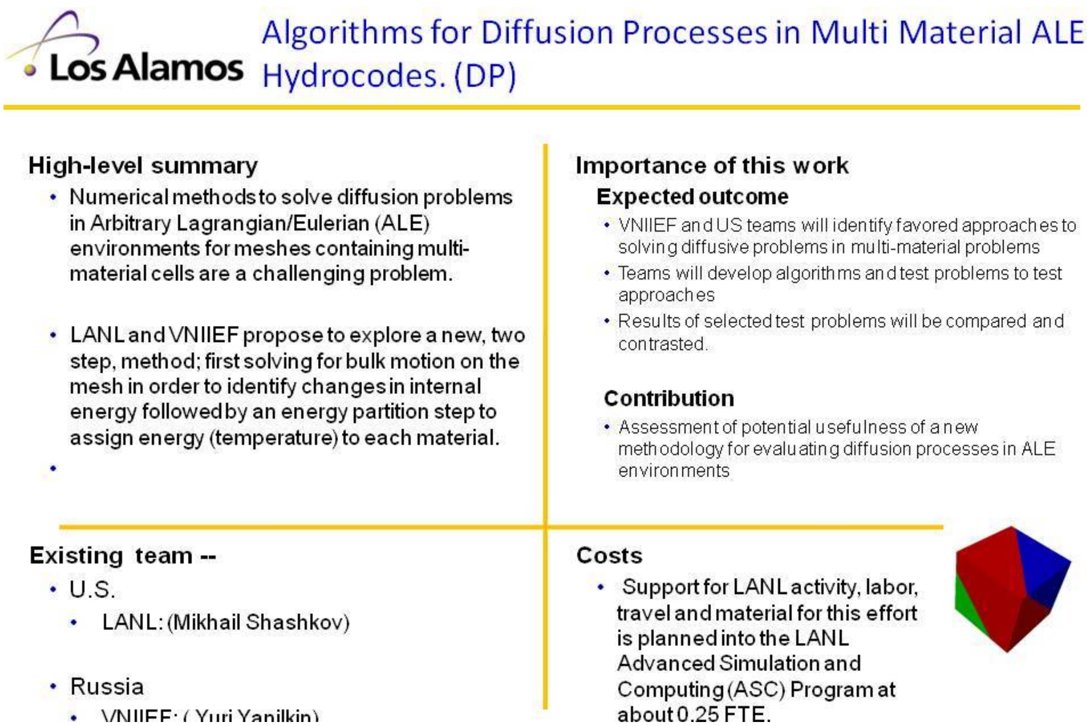

Fig. 8. Exploring algorithms for modeling diffusion processes

Similarly Sandia is interested in joining the MHD effort, adding yet more simulation capability with Sandia models and codes (Fig 7). Such cooperation offers the possibility of making a link with Sandia Z experiments. In the future, other links with both the technology and experiments planned at the Baikal facility should also be considered. Sandia participation will also bring some new Sandia staff into the discussion. Sandia is exploring the application of imploding liners in non-impact configurations as platforms for isentropic compression, and for access to off-hugoniot states. Modeling ALT-3 liner implosion behavior will contribute to the development of an isentropic compression platform.

While the ALT-3 experiment has been in development for several years under the Lab-to-Lab paradigm, the area of computational physics, computational methods and algorithms, has seen less activity as cooperative projects in the past, and the area of high performance computing and computer architecture has seen virtually none at all. LANL and LLNL together offer a total of four possible projects, which grew out of the detail discussions at the last Khariton Readings when David Daniel, Nathan Debardeleben(LANL), Aaron Miles (LLNL) and Jim Kamm (SNL), and Ray Lemke (SNL) visited Sarov in March 2013.

Last year's discussion led to the formulation of one possible project, (Figure 8) aimed at developing computational physics algorithms for handling diffusive processes in Arbitrary Lagrangian-Eulerian (ALE) hydro-codes. This is particularly challenging when the problem requires handling multiple materials in the cells of the mesh, and a new, two-step approach has been proposed by Yuri Yanilkin. A joint project consisting of the independent development of algorithms and test problems in the US and Russia followed by the comparison of results to evaluate the new methodology is being developed.

In parallel with the work on diffusion issues in ALE codes, are questions of how to approach the problem of large external forces leading to large deformation, and high strain rates, in the material in Lagrangian calculations. Deformation and tangling of the mesh is a well known limitation of Lagrangian computational techniques and the introduction of restructured grids is one approach to addressing those limitations. But for large and complicated problems re-mapping the physical variables from one grid to the new, restructured grid, is a challenging problem. A related issue is that of developing contact algorithms for handling the interface of multiple materials in such complex Lagrangian meshes. Jerry Brock, Tony Zocher and others at LANL are interested in exploring these issues along with Sergey Sokolov in Sarov (Figure 9).

In the US, developers of future computer hardware capability and future operating systems are exploring the concept of co-design which is the intersection of development efforts in hardware, software,

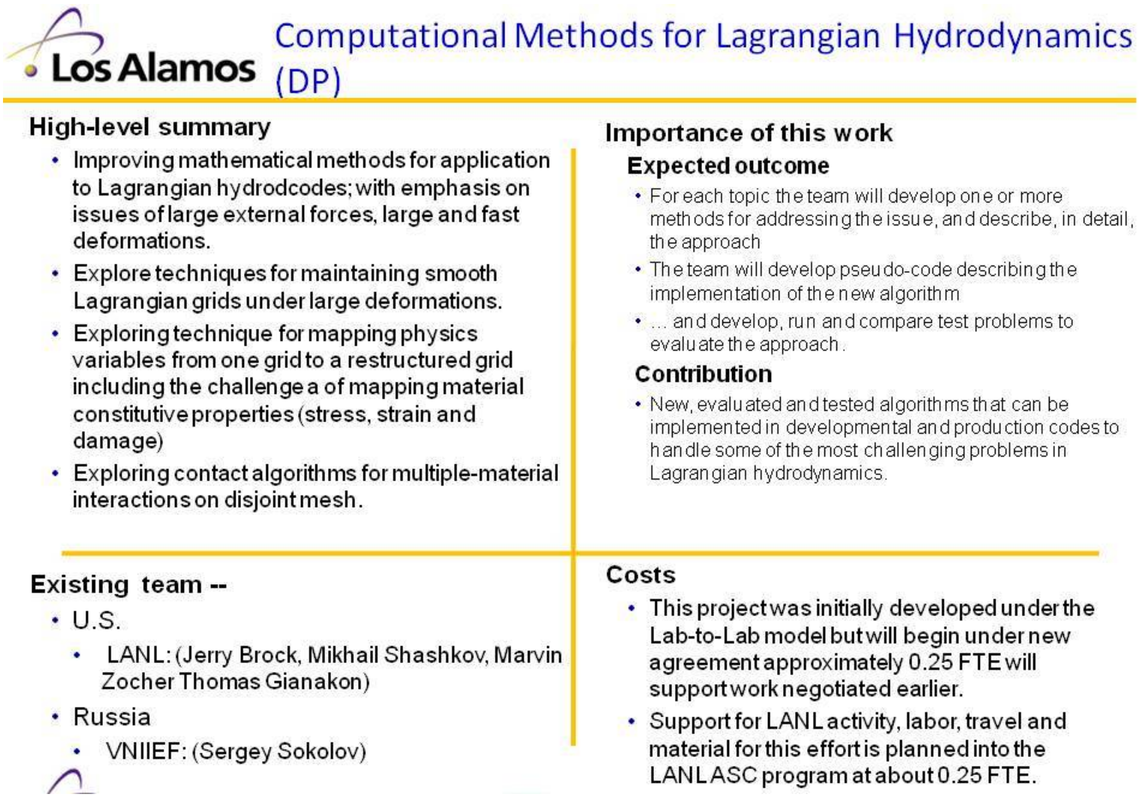

Fig. 9. New Methods in Lagrangian Hydrodynamics can be developed

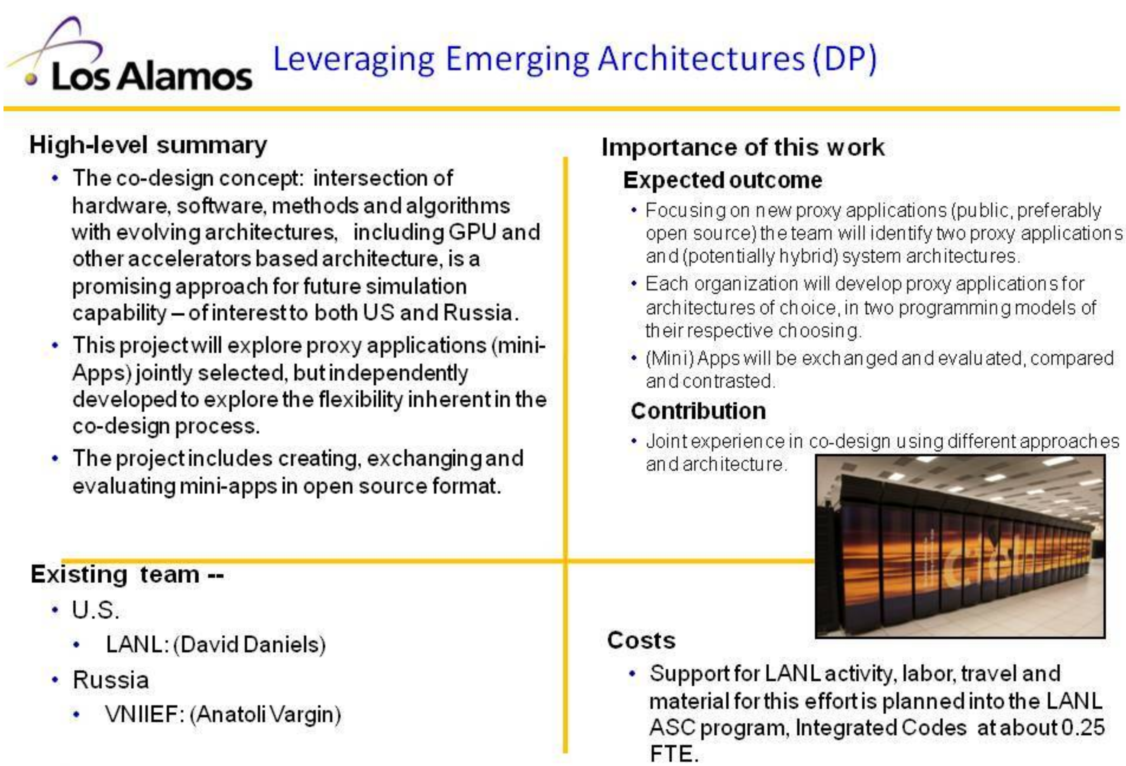

Fig. 10. The concept of “co-design” can extent the performance of next generation

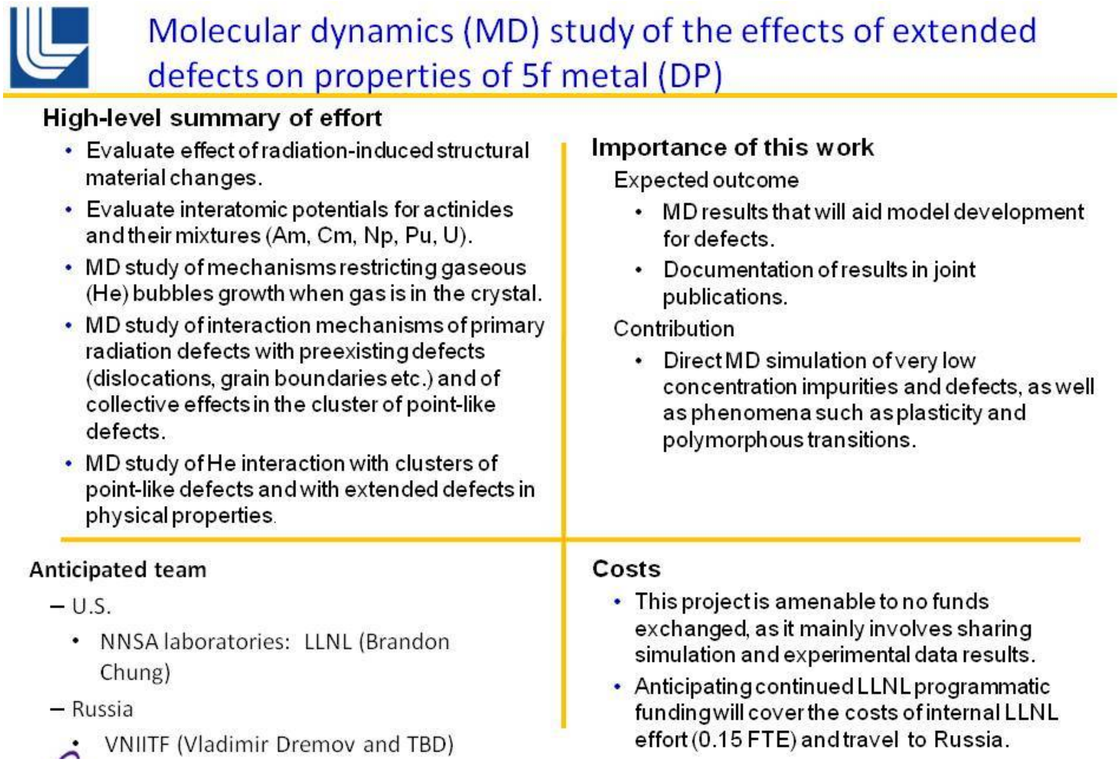

Fig. 11. Molecular Dynamics (MD) simulations to explore properties of f-electron

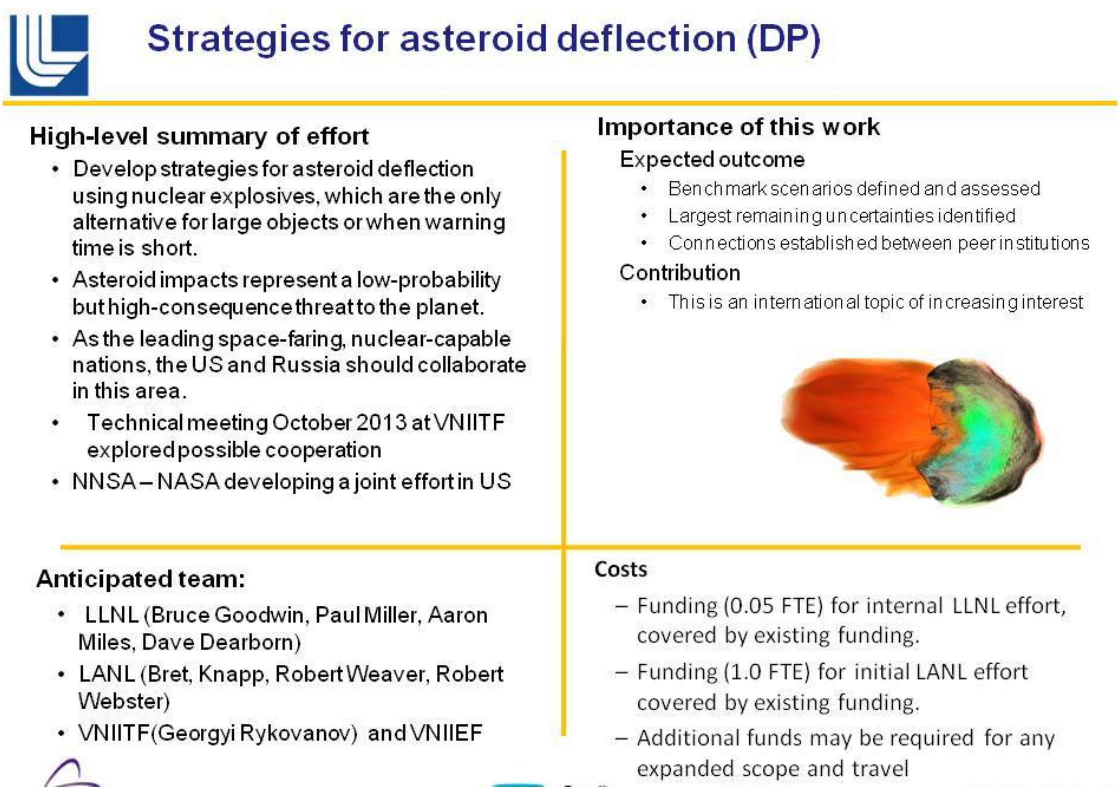

Fig. 12. Protection of the earth, and society, from impact by potentially hazardous space objects is a problem of global significance

methods and algorithms with evolving architectures, including GPUs, and other accelerator based architecture. David Daniels, and now Mike Lang, from Los Alamos are interested in developing a project to explore proxy applications in which small, discrete, applications will be jointly selected, but independently developed and then compared to explore the flexibility inherent in the co-design process in an open source format.

On a slightly different note but following the theme of advanced simulation and computing, the development of ever-larger, high-performance computing platforms has made possible atomistic-level, molecular dynamics simulation of progressively more physically complicated processes.

Brandon Chung in Livermore is interested in exploring additional application of molecular dynamics (MD) simulations including exploring the effects of radiation-induced changes to material structures; developing inter-atomic potentials for actinides and mixture of actinides; aspects of helium bubble growth in actinide lattices; and the interaction of radiation induced defects with pre-existing defects in materials (Fig 11). Several of these applications of MD are related to problems that have been explored by both LANL and LLNL along with VNIITF and VNIIEF over the last decade, under the former Lab-to-Lab paradigm, and this is another case where a multi-lab effort could possibly be formulated.

Preventing the impact of potentially hazardous space objects upon the earth is a problem of worldwide significance as we were reminded just last year in Chelyabinsk. Asteroid impacts are low probability events with potentially very high consequences and pose serious risks. Bruce Goodwin from Livermore and Bob Weaver from Los Alamos are working with Professor Rykovanov at VNIITF and with specialists in VNIIEF to evaluate strategies for asteroid deflection, including strategies that can be used to alter the orbit of large objects or that can be applied when warning time is short (Fig12). In the US, additional links between NNSA and NASA programs are also developing. In a meeting in Snezhinsk in October 2013, and in subsequent communication, a plan to develop some insight by looking at a few of the better known asteroids such as Bennu is taking shape.

In addition to the three focus areas: MHD; computation physics, methods and computer

In addition to three focus areas: MHD; computation physics, methods and computer systems; and asteroid protection, two other projects have been offered for consideration as well. Livermore is interested in testing new organic scintillators for next generation radiation detectors. Natalia Zaitseva in Livermore is interested in exploring the possibility that VNIIA

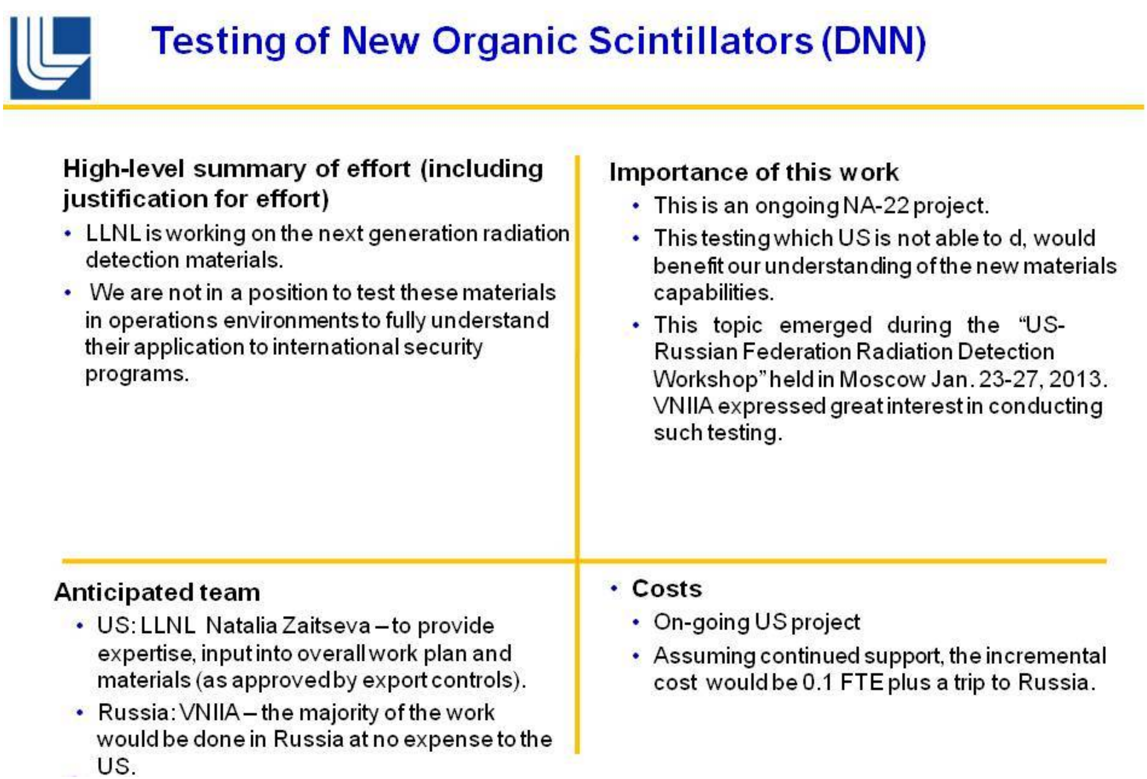

Fig. 13. New scintillators are needed to counter proliferation and potential terrorism

might be able to conduct characterization tests of some new material in operational environments to which the US does not have easy access. (Fig 13).

SNL and VNIIA have been working to draft a set of joint US-Russia Nuclear Warhead Security Principles that will articulate high-level best practices for warheads in storage and transportation. This effort will articulate a shared vision of the fundamental principles and objective of NW security. Joe Saloio in Sandia and Andrey Sviridov in VNIIA have been engaged in this effort under the former Lab-to-Lab paradigm -- work which can now be included in plans under the new Agreement (Fig 14).

While these 10 projects have been formulated to the point where work can begin if agreement were reached, their existence does not preclude continuing, informal, discussion of other areas for cooperation in the core competencies of the NNSA Laboratories and RFNCs including, for example: energetic materials, nuclear criticality, dynamic radiography, and non-nuclear or fundamental physics research and testing. While potential co-operation in these areas will require NNSA, and presumably ROSATOM, review and approval we should not lose sight of them in either the near- or intermediate- term.

Fundamental work in energetic materials (Fig 15) is an area which has not been developed in previous lab-to-lab engagements though at least LANL in the US and VNIIEF in Russia have regularly expressed interest in the topic. Experimental measurement and simulations addressing initiation, detonation kinetics, failure behavior and excited state properties of common energetic materials could be a starting place for energetic materials work . Safety and sensitivity characteristics are also of interest, as are explosive-metal interactions – the details of how explosives deliver energy to, and accelerate, metals. Understanding “home-made” explosives and the detailed operation of improvised explosive devices spans the efforts, and interests, of both the fundamental science and global security communities.

Fundamental work in nuclear criticality was explored as a topic for cooperation, briefly in 2007–2009 by LANL and VNIIEF with exchanges of data, and results from neutronic simulation of static benchmark experiments, conducted to validate new ENDF/B-VII nuclear cross section data. Los Alamos has since completed the re-location of its criticality experiments to the Nevada National Security Site. Recently, VNIIEF has expressed some interest in considering work aimed at determining the critical mass of Neptunium-237 and LANL would like to follow up on that interest when the opportunity permits. Finally, international cooperation in training, and exchange of information about best approaches to operational issues has a long history of success, and while more technological than fundamental, such exchanges can also be an important avenue of exchange for the future.

Dynamic X-Ray radiographic sources, such as DARHT, shown in Figure 17, detectors, recorders and

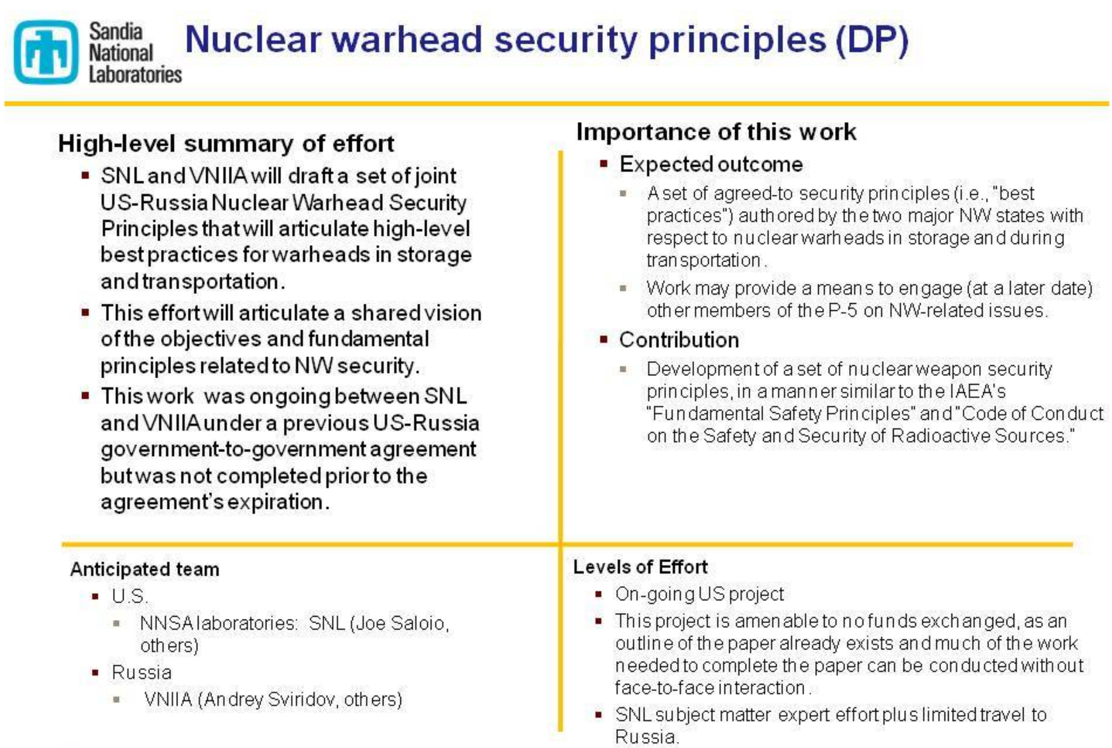

Fig. 14. Nuclear Security Principles

Fig. 15. Fundamental work in energetic material can take many forms

Fig. 16. Fundamental work in nuclear physics and criticality can also be discussed

Fig. 17. Cooperation in radiographic technology can be fruitful, while still respecting sensitivities

data analysis techniques and algorithms for penetrating radiography could also be explored as topics for cooperation while continuing to respect mutual sensitivities. When meeting in Los Alamos in 2011, the Russian Lab directors toured the DARHT facility and when the directors met in Sarov, in 2012, the US directors were also able to tour some VNIIEF x-ray facilities. Certainly VNIIEF leads the world in betatron technology for radiographing fundamental dynamic experiments and discussions exploring our mutual interest in radiographic technology may be of interest in the future.

Both US and Russia have presented results of dynamic radiographic experiments using proton beams instead of x-rays since at least 2010. At LANL, we use the LANSCE 800 MeV proton beam for a variety of condensed matter and material dynamic experiments, looking at detonation and shock processes in

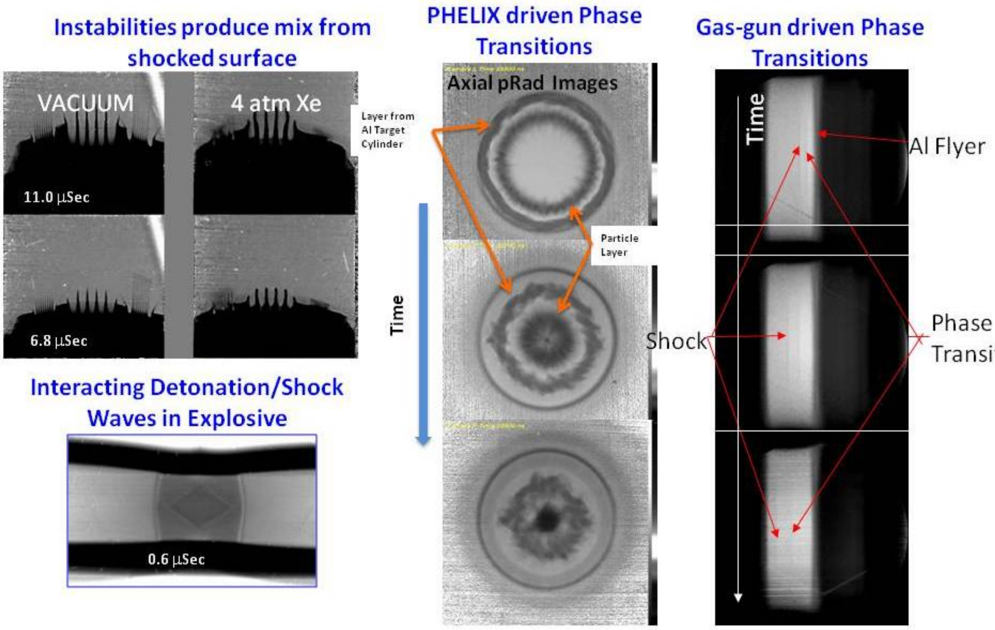

Fig. 18. Proton Radiography is an alternative to traditional X-Radiography for some applications

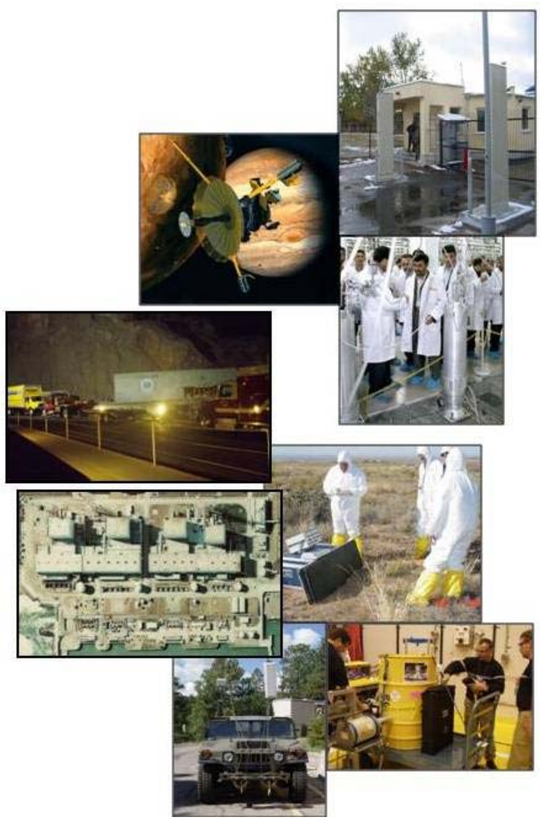

Fig. 19. Opportunities in Global Security, nuclear counter proliferations and nuclear counter-terrorism

explosive, instabilities in dynamic materials experiments implosion physics and shock-wave physics. VNIIEF has presented similar results using much higher energy protons. We continue to discuss a possible family of experiments that could compare and contrast proton radiographic techniques at significantly different proton energies.

Of particular interest to the electro-physics community may be the recent successful integration of a pulsed power implosion driver, the PHELIX (Precision High Energy Liner Implosion Experiment) driver, with p-Rad diagnostics. The images in the center column of Figure 18 are from the first PHELIX-driven, Damaged Surface Hydrodynamics experiment conducted within the last few months and LANL is prepared to offer the option of using PHELIX and *p*-Rad for joint experiments.

It would be inappropriate to end a discussion of the prospects for cooperation without some reference to the wide range of possibilities in the area of Global Security including nuclear counter-proliferation, nuclear security and nuclear counter-terrorism. Though engaging a different community than that represented at this conference, I think possibilities exist in material science, safeguards and security, treaty verification and in system analysis including risk assessment methodologies. Some of those engagement are already well established and others may be possible in the future.

Summary

So, for both the RFNCs and the NNSA laboratories the new Agreement forms a roadmap for future cooperation now and in the future. We will need to look for future opportunities for productive expert-to-expert discussions. NNSA has agreed to discussion, and planning in ten specific projects as we have outlined here, and yet other opportunities exist in such areas as energetic materials, criticality and radiography.

On a personal note, I would like to thank our many Russian colleagues for over 20 years of productive scientific and technical interchange in areas foundational to the work of our NNSA and ROSATOM institutions. I thank you for this opportunity to discuss our view of potential future cooperation and the entire US team looks forward to the next opportunity for planning discussions – and to fruitful cooperation in the future – as they have been in the past.