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A D SAKHAROV'S 90TH BIRTHDAY COMMEMORATION

Sakharov at KB-11. The path of a genius

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Contents

Abstract. 21 May 2011 would have marked the 90th birthday of Andrei Dmitrievich Sakharov, a towering 20th-century figure in science and human thought, whose ideas, research contributions, and life example exerted enormous influence on the history of the second half of the 20th century and, in particular, on the history of Russia. Whether as a scientist or a private person (including his public activities and exceptional attitude to human personality), he always displayed creativity and a freedom of spirit, thought, and action. Sakharov's life and creative work make him a model scientist and citizen for many and undoubtedly provide a legacy for the development of science and society in the 21st century. In this paper, some of Sakharov's key ideas and achievements relating to his KB-11 period are exemplified, and how they influence present day research and technology, notably as employed for affording national security, is examined.

1. Development of the *sloika*

In spring 1948, A D Sakharov formulated a new principle for producing a pulsed thermonuclear reaction, which became the most important contribution to the development of nuclear weapons in our country. Later on, he wrote about this: "After two months, I made a sharp turn in the work and proposed an alternative project of a thermonuclear charge, which was completely different... in the physical processes proceeding during the explosion and even in the main energy-release source. Below, I call this proposal 'the first idea'" ([1], p. 9).

A D Sakharov substantiated the physical principles of his proposal in the following way [2]:

"(1) In a *sloika* (Translator's note: named after a Russian layer cake), the local temperature equilibrium of matter and radiation is established. The question about the existence of such a detonation mode does not arise (this mode undoubtedly exists).... The width of the detonation wave zone is not very large.

(2) Thermal reactions produce fast neutrons in D, which can cause the fission of ^{238}U nuclei, resulting in a considerable increase in caloricity.

(3) The weak transparency of uranium to photons provides a moderate width of the shock wave zone moving ahead the burning zone.

(4) ...The temperature in adjacent phases is equalized by the heat conduction of radiation. Therefore, the equality of pressures in adjacent phases implies the equality in the number of particles in the U and D unit volumes; the ionized uranium 'swells', compressing D by its electron pressure...."

Sakharov's radical solution consisted first of all in passing to the ignition and burning of a compressed thermonuclear fuel, initially by a shock wave in the detonation mode and then by a process which was called 'sakharization', the conditions for them being produced by the heterogeneous structure of a system consisting of the thermonuclear material and uranium.

Primarily, A D Sakharov intended to make a large spherical uncompressed *sloika* with an initiating atomic bomb placed at its center. After visiting KB-11 (Design Bureau No. 11)[1] in June 1949, where he became familiar with the design of the RDS-1 device and discussed the problem with Yu B Khariton, Ya B Zel'dovich, and E I Zababakhin, Sakharov proposed the more efficient *sloika* design based on the implosion principle. An atomic detonator was placed at the center of the *sloika* surrounded by the layers of a thermonuclear fuel and uranium. The whole system was

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[1] Later, the All-Union Research Institute of Experimental Physics and, after 1992, the Russian Federal Nuclear Center — All-Russian Research Institute of Experimental Physics (RFNC–ARRIEP)

compressed with an explosive placed outside a multilayer system, while the *sloika* was initiated by implosion and explosion of an atomic detonator.

This was an exceptionally fruitful and pragmatic combination of the fundamental physical ideas of the *sloika* and implosion.

The principal features of the *sloika* allowed varying widely the features of its design and materials of its composition. The first such proposal was made almost at once after A D Sakharov's formulation of the main ideas. He wrote about this the following: "Soon my proposal was substantially supplemented by V L Ginzburg, who put forward 'the second idea' ([1], p. 9). On 3 March 1949, V L Ginzburg pointed out in the account, "The use of ^{6}LiD in the 'sloika'", "The advantages of using the deuterium-containing material $^6_3$LiD in the 'sloika' are noted. In this case, the reaction $^6_3\mathrm{Li} + ^1_0\mathrm{n} \to ^4_2\mathrm{He} + ^3_1\mathrm{H}$ produces tritium $^3_1\mathrm{H} \equiv \mathrm{T}$, which, taking part in reactions $\mathrm{D} + \mathrm{T} \to ^4_2\mathrm{He} + \mathrm{n}$ and $\mathrm{T} + \mathrm{T} \to ^4_2\mathrm{He} + 2\mathrm{n}$, yields neutrons producing uranium fission" [3].

These principles were fundamental for all the thermonuclear weapons, and they were first realized in practice in combination with gas-dynamic implosion (RDS-6s) and then with atomic compression (RDS-37), which was implemented by A D Sakharov and researchers under his supervision. All this determined the basic features and properties of thermonuclear modules of several generations of military equipment of our nuclear arsenal for a few decades, up to the present time.

A D Sakharov worked on the *sloika* in I E Tamm's theoretical group organized in summer 1948 to tackle the thermonuclear problem at the Lebedev Physical Institute, Academy of Sciences of the USSR (FIAN) and later, in early 1950, transferred to KB-11. A D Sakharov's attitude toward I E Tamm is characterized by his wonderful words: "I want to express my gratitude to I E Tamm who never spared either time or effort to put me on the right scientific path" [4].

"...We were all very lucky that Igor Evgen'evich happened to be nearby.... Near a blackboard in his office, we received the methodical lesson of theoretical studies. At conferences with authorities, we received the lesson of the businesslike, human, and scientific fidelity to principles. And in any circumstances, he gave us the lesson of good faith and thoughtful industry" [5].

A D Sakharov wholeheartedly adopted this style of scientific work and then cultivated it among his younger colleagues in our institute. This style became the fundamental basis for the efficient scientific search and practical realization of ideas for the development of many nuclear and thermonuclear weapon designs.

A D Sakharov and his colleagues were faced with extremely complicated problems. Here, I will point out only some of them. At the initial stage of the work, neither A D Sakharov nor I E Tamm nor V L Ginzburg knew about the unique quality of tritium as a thermonuclear fuel related to the fact that the rate of the tritium–deuterium (TD) reaction is two orders of magnitude higher than the rate of the deuterium–deuterium (DD) reaction. These data were classified and not available to them until May 1949. The required data on neutron-nuclear processes for TD neutrons and the conversion of neutrons to tritium on the ^{6}Li isotope were also absent. It was clear that hydrodynamic instabilities will develop in a layered system, their scale being rather uncertain. The data on the gas-dynamic implosion of layered systems were absent. To study the burning of nuclear and thermonuclear materials in the *sloika* and the energy release in it, sophisticated mathematical calculations were required to perform, which had no precedent. It was necessary to find out how nuclear tests should be conducted to reach a comprehensive conclusion about the quality of realization of thermonuclear burning.

By the summer 1953, all these issues were resolved. The answers to many of them were obtained within the framework of fundamental physics, and their importance lies in the fact that they laid the groundwork for the development of thermonuclear weapons in our country.

2. Creation of the RDS-6s *sloika*

On 15 July 1953 (less than one month before the test), an account with theoretical calculations substantiating the operation of a model of the RDS-6s hydrogen bomb (referred to as gadget in the confidential materials), signed by I E Tamm, A D Sakharov, and Ya B Zel'dovich, was written.

The account was called "A model of the RDS-6s gadget", although the tested model "does not differ from the military gadget except for the mass of active materials, which is 2–3 times greater in the military gadget." Below, we follow Sakharov's original text [6].

The account contained four main parts:

I. Operation principles and basic properties of the RDS-6s gadget.

II. Studies of the processes taking place during the operation of the RDS-6s gadget.

III. Analysis of the reliability of the RGS-6s gadget.

IV. Tasks and RDS-6s testing methods.

In part I, the basic principles of the physical layout of the RDS-6s gadget, thermonuclear reactions, the problems of tritium regeneration on the ^{6}Li isotope, and the fission of uranium nuclei by thermonuclear neutrons are considered.

The operational process of the gadget consisted of a few stages. The first was the implosion of the gadget by a spherically symmetric converging detonation of an explosive, ending with the operation of a neutron initiator, similar to the initiator in the first atomic bomb, RDS-1.

The second stage began with the initiation of a chain reaction in fission material and represented a nuclear explosion intended to stimulate a thermonuclear reaction.

The third stage began with an increase in temperature in the internal thermonuclear fuel, achieving a level sufficient for thermonuclear burning. This process led to the burning of uranium nuclei and the ignition of the next layer of the thermonuclear fuel. At this stage, the sakharization process became important.

In this part of the account, the expected energy release and its distribution over the main energy releasing layers are presented. These fundamental values were obtained from the 'exact' mathematical computation performed by L D Landau's group.

In the second part of the account with theoretical calculations, the authors pointed out: "At the beginning of the work on RDS-6s, quantitative data on basic processes determining the behavior of a nuclear detonation of the hydrogen gadget were missing, and thus it was impossible to calculate the power of the gadget and the amount of tritium required to make it.

To obtain these data, it was necessary to perform numerous experimental and theoretical studies and to improve considerably the accuracy of nuclear measurements and mathematical calculations."

The authors of the account point out that, to calculate the parameters of the hydrogen gadget, it was necessary to know first of all the cross sections for various elementary processes. "The most comprehensive investigations of the rate of the D + T reaction were performed at the Physical Institute, USSR Academy of Sciences (I M Frank's laboratory).... The results obtained considerably improve and correct data published in the foreign literature. The achieved accuracy is outstanding for such complicated investigations. These studies have shown with a complete confidence that the rate of the D + T thermonuclear reaction is extremely high, which is fundamentally important for the development of RDS-6s" [6].

The authors write about the fission parameters for uranium nuclei bombarded by thermonuclear neutrons: "Neither the fission cross section nor the number of secondary neutrons produced during the fission of ^{238}U irradiated by 14-MeV neutrons are published in the literature. These quantities were repeatedly and carefully measured at the Physical Institute of USSR AS, Institute of Chemical Physics, Laboratory of Measuring Instruments, Hydraulic Engineering Laboratory, and KB-11 and were found to be considerably higher than those for neutrons produced in the chain reaction" [6].

Then, the authors of the account write about the regeneration parameters of tritium: "The data on the interaction of neutrons with ^{6}Li available in the literature were inaccurate and contradictory. The cross section for the reaction of tritium production and neutron scattering was studied at the Ukraine Physical and Technical Institute and the Institute for Physical Problems. It was found that the cross section had a maximum at a neutron energy of about 250 keV, and data from the literature were quantitatively refined" [6].

An important part of experimental nuclear investigations comprised physical measurements with RDS-6s models, in which the numbers of ^{238}U fission events caused by TD neutrons and their 'offsprings' were determined. "The models were fabricated in numerous variations and consisted of layers containing uranium and a light material.... The great part of these complex and time-consuming experiments were performed in 1951–1953 at KB-11, the Hydraulic Engineering Laboratory, and FIAN. A method for calculating the number of fission events during detonation, based on the theoretical processing of these experiments, was developed" [6].

A separate group of model experiments was conducted to study the capture parameters for neutrons in ^{6}Li. Experiments in this area were performed at KB-11 using equipment developed at the Institute for Physical Problems of USSR AS. Some experiments were also conducted at the Hydraulic Engineering Laboratory.

An efficient and symmetric implosion was very important for the success of the project. The authors write in the account [6]: "Compression in RDS-6s proceeds somewhat differently than in gadgets tested earlier. These features of the compression process take place due to the presence of alternating light and heavy layers."

The results of implosion calculations were verified by several experimental methods. "Altogether, more than 300 experiments were performed with models during the development of the design and about 40 experiments with charges of natural size, but representing only a part of a sphere... for the convenience of observation and accommodation of the measuring equipment" [6].

The authors write about the influence of mixing: "Mixing is performed in two stages. In the compression stage, the interfaces of the layers become uneven and rough. In the nuclear detonation stage, all materials are transformed into gas; the interface roughnesses rapidly increase, leading to chaotic, turbulent mixing.

The theory of turbulent mixing was developed by S Z Belen'kii at FIAN by using experimental data obtained at KB-11 and LIPAN.[2] A commission organized at KB-11 considered the possible role of mixing effects and estimated that they can reduce the energy detonation effect by no more than 20–25%....The direct and indirect investigation of the role of mixing effect during nuclear detonation at testing ground No. 2 is becoming very important" [6].

The indirect answer to the influence of mixing was received from the results of RDS-6s tests.

Mathematical calculations were extremely important for understanding processes proceeding in RDS-6s and determining the parameters of the gadget.

"The presence of the layered structure in the system does not allow one to use averaged quantities and requires the knowledge of accurate values of temperature, material density, density of neutrons, etc. in each of the layers.

Methods for 'detailed' calculations of detonation processes were developed in A N Tikhonov's and L D Landau's groups on the orders by KB-11...

The development of these mathematical methods for detailed calculations for KB-11 required serious research and time-consuming calculations. In the course of the search for the optimal variant of RDS-6s and methodical investigations, 12 detailed calculations of hydrogen gadgets were performed (7 calculations at A N Tikhonov's bureau, 3 calculations at L D Landau's bureau, and 2 calculations at K A Semendyaev–I M Gel'fand's bureau). The number of arithmetical operations performed during these computations amounted to many tens of millions.

Note some principal moments. A method of calculations was developed in which small errors unavoidable in such cumbersome calculations are not accumulated and do not produce a considerable error in the final result. This method offers, in particular, possibilities for using electronic computers instead of slow and time-consuming manual calculations" [6].

The main task of the RDS-6s test was to produce a nuclear detonation using a thermonuclear reaction. Along with the measurement of the total energy release, it was necessary to obtain data on the rate of the thermonuclear reaction and its proceeding conditions. It was assumed that "these data will provide the possibility for the reliable design of RDS-6s gadgets of any power and size" [6].

Testing ground measurements included:

(i) the determination of the total energy release in the explosion;

(ii) radiochemistry measurements of the composition of materials produced during the detonation of RDS-6s, including the measurement of activation of special detectors placed in the gadget;

(iii) temporal characteristics of the detonation process;

(iv) investigations of the action of the shock wave and parameters of γ-rays and neutron radiation.

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[2] The Laboratory of Measuring Instruments, USSR Academy of Sciences; today — National Research Centre 'Kurchatov Institute'. (*Editor's footnote*)

The RDS-6s test performed on 12 August 1953 completely confirmed the physical and constructive principles of the hydrogen bomb and its calculation methods. The total trotyl equivalent measured by different methods was 400 kt, coinciding within the measurement accuracy with the calculated power. The first thermonuclear module was created, whose significance is difficult to overestimate in light of the further development of thermonuclear weapons.

The outstanding successes of researchers and engineers in the development and testing of improved atomic bombs and the first thermonuclear bomb in the period from 1948 to 1953 had important scientific, technological, and political significance and were highly regarded by the USSR Government.

The main developers were awarded the Stalin Prizes of different classes and the highest decorations of our country. A D Sakharov's contribution was especially recognized. He was awarded the Stalin Prize of the First Class (with remuneration equivalent to a ten-year salary), received the title of a Hero of Socialist Labor, and was elected Full Member of the USSR Academy of Sciences, passing the step of Corresponding Member.

3. Atomic compression

The successful test of the *sloika* solved the formulated practical problem. However, two problems remained unsolved:

(i) the exclusion of large amounts of tritium from the composition of a thermonuclear charge with the power of ~ 1 Mt;

(ii) the development of multimegaton thermonuclear charges within the framework of existing restrictions imposed on the size and mass of the gadget by the carriers.

Initially, A D Sakharov and his colleagues attempted to solve these problems by optimizing the *sloika* under conditions of gas-dynamic implosion. However, they soon understood that it is necessary to achieve a considerably higher compression of the thermonuclear material compared to that obtained by utilizing ordinary explosives for compression.

"Already in the first months of new 1954, we theorists at the object understood that my proposals... promise nothing good... At the same time, we proposed a principally new idea which was conditionally called 'the third idea'. This idea had already been discussed earlier, rather as a wish, but in 1954 these wishes became a real possibility" ([1], pp. 10, 11).

The idea was to replace the hydrodynamic implosion of the *sloika* by its atomic compression. Initially, in January 1954, A D Sakharov and Ya B Zel'dovich considered the conceptual feasibility of compressing the *sloika* by gas-dynamic products of the nuclear explosion.

It was proposed to design the physical layout of the secondary module based on the analogue of the internal part of the RDS-6s charge, i.e. the 'layered' spherical system. It should be noted that it was an extremely complex system from the point of view of real computational capabilities of that time. The main problem was how to provide in such a charge the compression of the secondary module close to the spherically symmetric regime.

After that, the atomic compression acquired its canonical form in which X-rays were considered carriers for energy from the primary charge to the thermonuclear module. To produce the directional energy transfer, A D Sakharov proposed placing the primary and secondary modules inside one shell, which provided good reflection for X-rays. Inside the charge, conditions were established for the efficient transfer of X-rays in the required direction.

A D Sakharov described the development of the atomic compression idea in the following way:

"It seems likely that a few researchers in our theoretical departments came simultaneously to 'the third idea'. I was one of them. It appears to me that I understood the basic physical and mathematical aspects of 'the third idea' already at the early stage. Because of this, and also due to my authority acquired earlier, my role in the adoption and implementation of 'the third idea' was possibly one of the decisive ones. However, undoubtedly the role of Zel'dovich, Trutnev, and some others was also very important, and maybe they understood and foresaw the prospects and difficulties of 'the third idea' no less than I did" ([1], pp. 10, 11).

The third idea appeared as a fundamental scientific answer to the practical requirement of creating a qualitatively new universal thermonuclear weapon. This idea allowed us to exclude large amounts of tritium from thermonuclear charges and create multimegaton thermonuclear charges.

"Yu B Khariton, who trusted theorists and believed in a new line of inquiry, took a great responsibility on himself by sanctioning the reorientation of work at the object.... Kurchatov also knew about the course of events... Formally, our activity was blatant self-government.... Malyshev visited the object....[3] His speech was long and had no effect at all. We all retained at our opinion... Kurchatov decisively took our part" ([1], pp. 10, 11).

The path to practical realization of atomic compression was open, and the task was accomplished by the successful confirmation of this principle in the RDS-37 test on 22 November 1955.

The contribution of A D Sakharov to the development of the atomic compression principle and the RDS-37 gadget was highly regarded. He received the second title of a Hero of Socialist Labor and became, together with Ya B Zel'dovich, Yu B Khariton, and I V Kurchatov, one of the first laureates of the newly founded Lenin Prize, which was given him "for the development of physical principles and theoretical calculations of the RDS-37 gadget" [7].

The principle of atomic compression became the basis for the development of particular prototypes of military equipment for strategic nuclear forces and many complexes of nonstrategic weapons, while the RDS-37 gadget is rightly considered the prototype of the domestic thermonuclear weapons providing nuclear parity and nuclear deterrence guarantees.

4. Creation of a superbomb and development of new types of thermonuclear weapons

Consider briefly the history of the development of the superbomb.

The thermonuclear project appeared from the very beginning as the project of a superbomb, i.e. a bomb with a multimegaton energy release. The initial project based on the detonation of liquid deuterium, Super in the USA and 'Tube' in the USSR, was namely such a project. The initial choice of a *large sloika*, not using implosion, was also such a project.

In 1954, Edward Teller proposed the idea of the possibility of developing a thermonuclear charge providing

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[3] V A Malyshev was the Minister of Medium Machine Building of the USSR.

an energy release of up to 10,000 Mt. In 1956, the Pentagon formulated the requirements for 100-Mt warheads, and the Los Alamos Laboratory substantiated the possibility of creating a 1000-Mt thermonuclear charge.

After the creation of RDS-37, the superbomb issue was considered again at a completely different level. In early 1956, A D Sakharov, Ya B Zel'dovich, and V A Davidenko proposed developing a series of superpower hydrogen bombs based on the atomic compression principle providing an energy release of up to 1 billion tons in the trotyl equivalent. This was the urgent proposal in response to the enormous increase in the thermonuclear arsenal in the USA, which achieved ~ 9 billion tons in the trotyl equivalent.

Initially, the 30-Mt superbomb was developing at the NII-1011 (Research Institute No. 1011)[4] (project No. 202). However, this project was cancelled.

After the end of the moratorium in 1961, KB-11 returned to the question of developing the superbomb. Now, it was entrusted with creating a 100-Mt thermonuclear charge (project No. 602). Original solutions and accumulated experience allowed researchers and engineers to realize very rapidly this development, and the charge was successfully tested on 30 October 1961. Beginning in 1961, increases in the megaton-range nuclear arsenal of the USA ceased.

The full-scale test of a 100-Mt charge would result in a considerable radioactive yield determined by the ^{238}U fission products. The danger was aggravated by the fact that the height of the explosion of a dropped aerial bomb was insufficient to exclude the touch of an explosion fire ball with Earth's surface, which would considerably increase the radioactive contamination. A D Sakharov proposed and realized the test of the superbomb at less than full scale. Uranium-238 in the thermonuclear module was replaced by passive, nonfissile, and weakly activated materials. The reduction of the energy release to 50 Mt excluded the touch of the fire ball with Earth's surface. Thus, despite the huge energy release, this test was comparatively ecologically safe.

In 1961–1962, A D Sakharov was in charge of the development and successful tests of a few dozen thermonuclear charges of different types, which became the foundation of our nuclear arsenal until the mid-1970s. Importantly, all these charges were based on the sloika and atomic compression principles. The tests of these charges gave unique experimental material about the features of pulsed thermonuclear burning, which is widely used at present in different tasks related to maintaining the nuclear arsenal of Russia.

For his work on the creation of the superbomb and supervision of the development of thermonuclear charges, A D Sakharov was awarded a third Hero of Socialist Labor title.

At this period, A D Sakharov was the head of the theoretical department responsible for the development of thermonuclear weapons. I D Sofronov, an outstanding mathematician and organizer of mathematical studies at the RFNC–ARRITP, wrote the following about the working style of A D Sakharov as the head:

"Andrei Dmitrievich invited me in early 1961. He explained that the Government was considering the question about a long moratorium.... We should prepare for it... and develop for a short time many new constructions and test them.... Sakharov enumerated the approximate number of calculations of different types and the desired schedule of their fulfillment" [8]. And below he continued:

"Before the emergency work, A D gave the impression of a rather phlegmatic man, who was sitting, as a rule, in his office and was somewhat 'aloof from the world'. However, during the emergency work period, he changed and became the strong-willed and energetic leader who was completely on top of all the work. His voice acquired new strength. Every morning he... invited all the participants of the emergency work and gave them clear instructions. Sakharov gave the impression of a general guiding a battle" [8].

5. Fundamental physical ideas suggested by A D Sakharov during his work at KB-11

In 1950, A D Sakharov formulated the most important idea for the projects of 'continuous' thermonuclear energy production — the idea of magnetic plasma confinement, and outlined the general features of a magnetic thermonuclear reactor (MTR) which became the prototype of tokamaks and the modern project of the International Thermonuclear Experimental Reactor (ITER).

A D Sakharov's studies in 1950 in the field of explosive implosion, on the one hand, and on using a magnetic field for thermal insulation of plasma, on the other hand, undoubtedly initiated his new fundamental idea of magnetic cumulation (MC), i.e. the conversion of the explosion energy to magnetic field energy. A D Sakharov formulated the idea of "compression of a bundle of magnetic lines of force by the moving metal walls of a cylinder" and proposed conceptual schemes of devices for practical realization of this idea ([1], p. 79) to obtain superstrong megagauss-range magnetic fields (MC-1 device) and high-intensity megaampere-range currents (MC-2 device), based on the explosive action on 'current-carrying circuits'.

These proposals were then extensively developed at the RFNC–ARRIEP. At present, magnetic explosion generators (MEG) are used in various fields, from fundamental studies of physical properties of materials under extreme conditions to the investigation of the formation processes and action of electromagnetic pulses. This is a large field in physics in which our Institute has occupied a leading position in the world, while work based on MEG technologies is the direct creative legacy of A D Sakharov.

A D Sakharov was the originator of laser fusion.

"In 1960–1961, I again made a proposal concerning a controlled thermonuclear reaction. At this time, a communication came that Maiman had created the first (ruby) laser in the USA. I gave a talk at our object in which I substantiated the possibility of using a laser to excite a thermonuclear reaction in small spheres containing a thermonuclear fuel and compressed due to hydrodynamic effects during the pulsed heating of the external surface of spheres by the laser beam. I presented estimates of the parameters required for such devices. Later on, these estimates were refined in a series of numerical computer-aided calculations performed by my collaborators.... I specified power engineering as a possible field for application of this principle..." ([1], p. 36).

These ideas were extensively developed at the RFNC–ARRIEP. We have built a number of high-power laser facilities at which we performed and are performing now

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[4] Today — the Russian Federal Nuclear Center 'Zababakhin All-Russian Research Institute of Technical Physics' (RFNC–ARRITP). (*Editor's footnote*)

unique experiments with microtargets of different types, including thermonuclear microtargets.

At present, the outlook for studying the properties of materials under extreme conditions is related to the use of high-power megajoule-range laser facilities. Such facilities are being constructed in the USA, France, and China. The absence of such a facility in Russia inhibits achievement of unique fundamental results in this field. In the last year, a crucial decision was announced to build a megajoule laser facility at the RFNC–ARRIEP.

6. Initiatives in nuclear test and nuclear arms limitations

The name A D Sakharov is related to a number of important stages in nuclear arms limitation.

In 1958, he initiated a wide discussion of long-term radiological hazards caused by the action, in particular at the genetic level, of radiocarbon C-14 accumulating in the biosphere after atmospheric nuclear tests. This was an important argument for the atmospheric nuclear test ban.

At a period from 1958 to 1961, the USSR, USA, and Great Britain imposed the three-party nuclear test moratorium.

A D Sakharov played an important role in the 1963 Treaty Banning Nuclear Weapon Test in the Atmosphere, in Outer Space and Under Water, signed in Moscow. He wrote later: "I believe that the Moscow Treaty has historical significance. It has preserved hundreds of thousands and possibly millions of human lives that would inevitably perish during these tests.... But maybe even more important is that this is a step toward reducing the danger of world thermonuclear war. I am proud of my involvement in the Moscow Treaty" [9].

A D Sakharov was one of the initiators of the limitation of the development of antiballistic missile defense (AMD). He wrote in 1967:

"Let me explain briefly my opinion about the essence of the issue....

...Protection from a strike of a small number of enemy and provocateur missiles... on any, preliminarily unknown target... is technically possible; however, one should understand that the solution of even this 'simplified' problem will require very large investments of intellectual and material resources at a great scale comparable to the development of the offensive massive strike system. This includes the construction of a huge network of stations for enemy missile detection and antimissile guidance, of computational stations and communication lines, the development of methods for separating false aims, and the creation of highly maneuverable antimissiles... used at near and distant defense frontiers" [10].

"Although the AMD system in itself is not intended for assault or aggression, it can serve for aggressors as a means providing impunity, thereby increasing the temptation of a preventive war. Therefore, the refusal of the USSR and USA to enter into AMD would be a spectacular demonstration of their readiness to coexist.

The absence of a moratorium treaty will lead to a race of not only defensive but also offensive systems, which would be ramped up to guarantee a defensive breakthrough. Such an outcome is unprofitable for us economically, politically, and strategically... reducing the possibility of a 'general political settlement' " [10].

"...Offensive arms exhibit a so-called 'saturation effect' — if you can annihilate the enemy, further strengthening changes almost nothing. However, AMD has no 'saturation effect', and the outcome of the competition is determined, on the contrary, by the relation of technical and economical potentials.... By signing the moratorium treaty, the USSR and USA thereby abandon the mutually menacing policies and the temptation of striking a preventive blow under protection of the antimissile 'shield' producing the illusion of security....

Such a treaty would encourage peaceful coexistence forces and facilitate further steps in the field of disarmament and the reduction of tension" [10].

The conclusions reached by A D Sakharov became, in fact, the intellectual basis for the position of our country with respect to AMD for many decades, even now.

These conclusions are still mainly correct today, as the USA has abandoned the AMD Treaty and is developing national and regional AMD systems employing space technologies.

Amazingly, many of A D Sakharov's achievements in science are ongoing and developing today. Tens of institutes and laboratories in many countries are involved in studies developing his ideas. I will end this small review with his words appealing to the future:

"It is known... that the USSR, the USA, and other countries are performing extensive work to achieve a thermonuclear reaction with the help of laser ablation (and by means... of some other inertial methods). However, I think that systems based on magnetic thermal insulation are most promising for large-scale power engineering.... I suppose that these will first be breeder systems in which the energy source will ultimately be a fission reaction. As for systems not using uranium and thorium... I assume they will use 'tritium breeding'.... It is quite possible that energy production in the 21st and following centuries will be based on controlled nuclear fusion facilities. My participation in the early studies on a controlled thermonuclear reaction is a source of great satisfaction for me" ([1], p. 36].

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