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SUBJECT

Prospects for Use of Liquid Propellants in Sea-Based Strategic Missiles

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Summary:

The following report is a translation from Russian of one of a series of TOP SECRET Soviet documents pertaining to the development of liquid rocket propellants and the strategic missile weaponry and rocket-space systems based on them. The document stems from a collection of reports delivered at an interagency, all-Union conference of leading representatives of the Soviet missile research and design establishment held 6-8 June 1978 under the auspices of the USSR Ministry of Chemical Industry and the State Institute of Applied Chemistry to discuss the status and prospects for development of programs dealing with liquid rocket propellants. This paper, written by V. P. Makeyev of the Design Bureau of Machine Building, discusses the problem of selecting a new liquid propellant for naval ballistic missiles in place of the standard pair AT (nitrogen tetroxide) + UDMH, which, according to the author, has been employed in sea-based missiles for more than 15 years. Consideration is given to the pairs VPV (highly concentrated hydrogen peroxide) + tsiklin and AT + lyuminal-A, the latter of which is said to be especially attractive from a number of standpoints. For instance, the use of AT + lyuminal-A would make prospective Soviet naval missiles superior to Trident 2-type counterparts in terms of tactical-technical characteristics. Makeyev briefly surveys the experience of this design bureau in developing liquid-propellant missiles for the Navy, starting with the R-13 missile delivered into service in 1961. A cutaway view is provided for the R-29D missile, together with basic specifications. The paper also lists various design, technological, and organizational measures that the Soviets have devised to ensure safe and reliable operation for submarine-based missiles.

End of Summary

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PROSPECTS FOR THE USE OF LIQUID PROPELLANTS IN
SEA-BASED STRATEGIC MISSILES

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Investigations of questions pertaining to the use of propellants in missile technology are of a multifaceted nature resulting from the need to comprehensively consider the requirements set for the type of armament, the characteristics of the propellant itself, and the effect of the type of propellant on the technical configuration of the missile and weapons complex as a whole. In order to have a clear understanding of the pros and cons of a particular propellant, a systematic analysis and comparison of the following major aspects of its application in a missile are essential:

-- the energy characteristics of the propellant and the extent to which they can be achieved in the missile's engines;

-- the operating characteristics of the missile complex resulting from the use of the given type of propellant;

-- the effect of the propellant on the technical configuration of the missile and complex as a whole, and its effect on the tactical-technical characteristics and performance of the complex;

-- the state of the raw material and industrial resources;

-- the prospects for improving the engines using the given propellant;

-- the prospects for replacing the given propellant with new types of propellants;

-- a comparison of the forecast of the development of specifications for prospective weapons complexes with prospects for the development and use of new propellants;

-- a consideration of the priority factor in tactical-technical characteristics /compared to/ foreign missile complexes and, above all, US missile complexes.

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It appears advisable to follow basically this kind of approach in examining the prospects for using liquid propellants in sea-based strategic missiles. Obviously, it is better to evaluate future possibilities on the basis of analyzing the use of liquid propellants in naval missiles over the entire history of their development and operation up to the present time.

Experience of the Design Bureau of Machine Building in Developing Sea-Based Ballistic Missiles with Liquid-Propellant Rocket Engines, and Data on Their Operation

The development by the Design Bureau of Machine Building of ballistic missiles for the Navy has a history of more than 20 years and starts with the development and delivery into service of the R-13 liquid-propellant missile of the D2 complex. This was a complex, intended for the armament of submarines, which underwent prolonged use in naval line units. The missile's engines operated on liquid propellant AK-27I* + TG-02. The complex was in operation over the period 1961 through 1974.

Table 1 presents an overall list of the naval liquid-propellant missile complexes developed by the Design Bureau of Machine Building and delivered into service.

Table 1

Naval Missile Complexes Using Liquid Propellant

Missile	Propellant	Year of delivery into service	Years in operation
R-13	AK-27I + TG-02	1961	14
R-21	AK-27I + TG-02	1963	15
R-27 R-27K	AT + UDMH	1967	10
R-27U	AT + UDMH	1972	5
R-29	AT + UDMH	1973	4
R-29R	AT + UDMH	1977	1

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* Translator's note: AK = nitric acid.

The R-21 missile complex is the first complex with underwater missile launching. This and all subsequent complexes up to the present are /still/ in service.

With the development of the R-27 missile began a period of intensive use of the propellant AT + UDMH* for naval ballistic missiles. This propellant has become the standard one for the present day. High energy characteristics and stability over a wide range of temperatures have been responsible for its use in missile technology. The utilization of propellant AT + UDMH has made it possible to build a series of modern naval missiles whose performance equals and, in a number of cases, surpasses that of foreign models (Figure 1). The missiles in question are the R-27, R-27U, R-29, and R-29R. Their high performance was produced primarily through engine improvement and high compactness in the configuration of the missile itself.

The R-29 missile is a typical representative of a modern sea-based ballistic missile in which the configuration solutions dictated by the conditions of placing it in a launch tube of limited dimensions are most clearly reflected. Such solutions as the "burying" of sustainer-stage engines in the propellant component tanks and the elimination thereby of the tail and interstage compartments, as well as the placement of the warhead material /boyevoye osnashcheniye/ in the recess formed by the forward end plate of the delivery vehicle were so effective for missiles of limited dimensions that they became classic ones which also determine the configuration of the sea-based liquid-propellant ballistic missiles being newly developed. The effectiveness of such solutions is governed above all by the liquid state of aggregation of the propellant.

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* Translator's note: AT = nitrogen tetroxide; UDMH is given as NDMG in Russian.

COMPARATIVE EFFICIENCY CHARACTERISTICS OF
DOMESTIC AND FOREIGN SEA-BASED BALLISTIC MISSILES
USING SOLID AND LIQUID PROPELLANTS

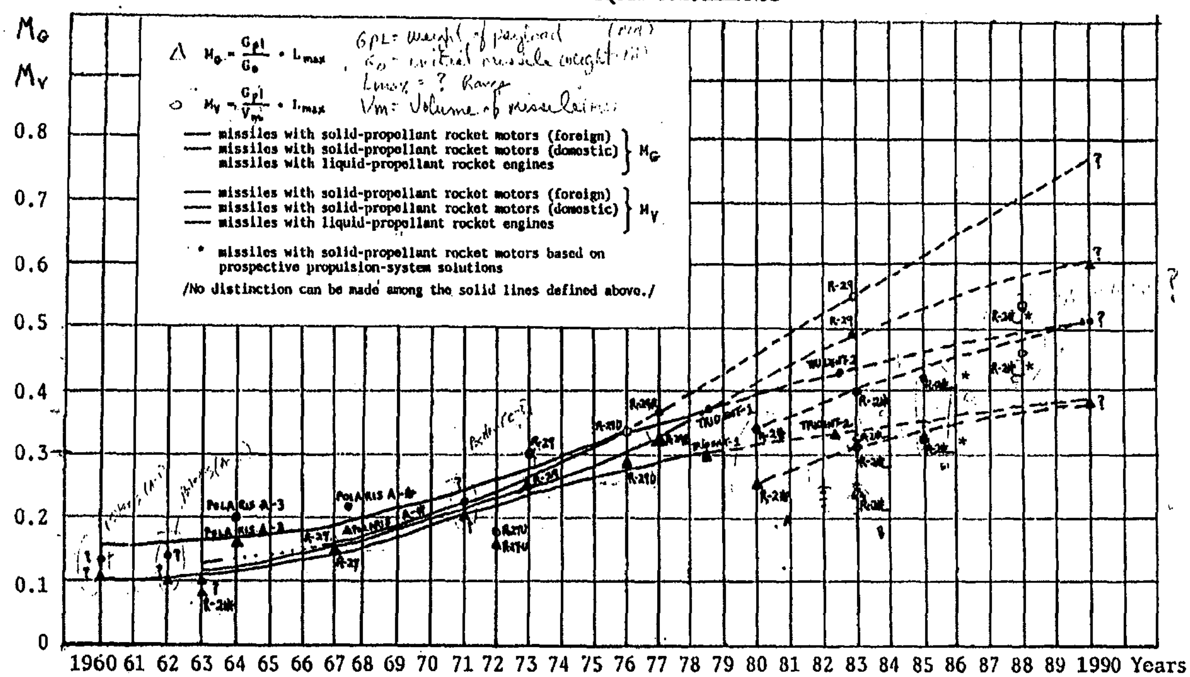

Figure 1

Translator's note: The legibility of this figure is very poor, and many designations can only be partially discerned: # = unintelligible numeral; _ = unintelligible letter; ? = entire designation unintelligible.

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It is significant that throughout a period of more than 15 years in the development of sea-based missiles, the propellant AT + UDMH has firmly maintained its position as the standard propellant, and the efficiency of its use has been increased from one missile to the next by means of improving the liquid-propellant engines primarily through increasing the operating pressure in the combustion chamber, starting from 100-130 atm (abs.) for the engines of missiles R-29 and R-27 to 275 atm (abs.) for the first-stage engine of the R-29RM missile now being developed by the Design Bureau of Machine Building (Table 2).

Table 2

Comparative Characteristics of Missiles
Depending on Combustion Chamber Pressure

	Missile					
	R-27	R-29		R-29RM		
	I stage	I stage	II stage	I stage	II stage	III stage
Vacuum thrust, t	28.8	70.2	13.7	91.1	40.0	10.0
Combustion chamber pressure, atm (abs.):						
-- of main unit	130	152	100	275	200	150
-- of control unit /rulevoy blok/	133	121	--	150	--	--
Vacuum specific impulse, sec	306.3	305.2	321	319.4	334	332
Relative mass of primed engine, kg/t of thrust	11.0	9.5	12.8	8.0	11.5	12.4

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-- providing successive prelaunch pressurization of missile tanks in order to prevent uncalculated pressure differentials on the end plates and shells of the tanks during failures in the shipboard system for prelaunch missile pressurization.

The enumerated set of measures has demonstrated its effectiveness in application to sea-based liquid-propellant missiles, has undergone sufficient testing over time, and is constantly being augmented by new measures that contribute to the further enhancement of missile safety and reliability.

The reliability of the naval missile complexes currently in operation is characterized by high indices. An analysis of materials pertaining to the operation of missile complexes with liquid-propellant missiles shows that the major portion of the failures which come to light during operation can be attributed to the control system equipment.

There are also failures of the liquid-propellant rocket engines, but their number is far lower than the number of failures in the control system equipment.

The operation of sea-based liquid-propellant missiles takes place under extremely harsh environmental conditions. On land, the storage temperature in depots ranges from 1° to 25°C, and the ambient temperature during loading and transportation -- from -40° to +50°C; wind velocity can reach 20 m/sec, and relative humidity -- 80 percent. In a submarine launch tube, the temperature ranges from 1° to 30°C; relative humidity reaches 80 percent and, at times, 100 percent (during spraying of the missile and flooding of the launch tube with water). Moreover, the service life of missiles is guaranteed for 10 years, five of which with storage in a submarine launch tube.

Throughout ten years of operating liquid-propellant missiles R-27, R-27U, and R-29 in submarines, there was not a single case in which component vapors appeared in a submarine launch tube from the ampulized missiles; i.e., when a missile is intact, its construction guarantees that there will be no leakage of components.

During the operation of the missiles, six cases in all were recorded that involved the catastrophic failure of missiles (due to the fall of a missile, unsanctioned pressurization of tanks, the effect of external overpressure). During the unfolding and overcoming of the emergencies connected with the catastrophic missile failures, there were no casualties and the working condition of the systems, components, and units was restored.

The emergency situations that occurred arose by reason of failure to fulfill the requirements, instructions, and work sequence set forth in the operational documentation, i.e., they were the consequence of incorrect actions by

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personnel. In this connection, measures are being implemented in operational and prospective complexes that are aimed at further automation of the work of servicing naval missiles.

The specific properties of the components in use and the presence of a liquid phase that rather readily turns into a vapor phase make it possible to continuously and efficiently monitor the condition of missiles, which, in turn, ensures the timely taking of measures to restore the combat qualities of missiles, eliminate the effect of a defective missile on the combat readiness of other missiles, and also prevent the carrying out of the prelaunch preparation of a defective missile and the buildup of a more serious emergency situation.

Thus, the more than 15 years of developmental experience reveals a sufficiently high level of safety and reliability for sea-based missiles in all stages of operation.

The succession of solutions developed earlier, in combination with further design, technological, and operational refinements in this direction, will ensure a high safety level for prospective naval complexes with liquid-propellant missiles.

Prospects for the Use of Liquid Propellants in Sea-Based Ballistic Missiles

The standard propellant AT + UDMH which has been employed in naval missiles is still regarded today as one of the basic propellants for the immediate future in the development of missile complexes. Its use in a prospective missile in the sustainer stages of liquid-propellant rocket engines with high pressure levels in the chambers (Table 2) will make it possible to produce an increase of up to 3 percent in the specific impulse for each stage, which is one of the most important factors ensuring the fulfilment of the TTT specifications of the customer.

In view of the possibility of using titanium alloys in the construction of liquid-propellant rocket engines, it is proposed to fill the prospective missile with atin*. This will require accomplishing the task of ensuring the compatability of atin with the titanium material of the liquid-propellant rocket engines under high pressure and temperature conditions, as well as the task of making possible the prolonged use of atin in the tanks of an ampulized missile with air present in the cushions of the tanks.

Further possibilities for increasing the power generation of liquid-propellant rocket engines using the propellant AT + UDMH have already been largely exhausted. Therefore, as concerns the more distant future, it is proposed to use new propellant components.

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* Translator's note: Atin = AT + a corrosion inhibitor (nitric oxide).

The use of toxic, hypergolic, corrosively active components such as AT and UDMH naturally requires the realization in missile complexes of the design, technological, and organizational solutions that ensure safe and reliable operation of missiles in all stages of their service life. These questions are of particularly vital importance for the naval missiles to be placed in submarines since the safety of each missile is one of the factors determining the survivability of a submarine.

From the very beginning of the development of sea-based missiles, the Design Bureau of Machine Building has paid close attention to ensuring their safe operation. The first design solution in this direction was the complete ampulization of missile tanks with the elimination of detachable connections and their replacement with welded joints. This solution was first achieved in the R-27 missile; it was officially approved and has been used in all missiles subsequently developed.

The most acceptable structural material for the body of sea-based missiles is the aluminum-magnesium alloy AMg-6. It is stable when exposed to the corrosive components AT and UDMH and is resistant to the increased humidity in submarine launch tubes. So far there is no sufficiently effective substitute for this structural material.

Among the other design measures for ensuring the safety and reliable operation of sea-based liquid-propellant missiles, the following should be included:

-- double-layered divider end plates between the different propellant components (that make it possible to simultaneously increase the safety of a liquid-propellant missile and the compactness of its configuration by eliminating from the structure the compartments between tanks, which is extremely important under conditions of limited missile length);

-- dual pipelines for supplying one propellant component, with the lines passing through the tank containing the other component;

-- making it possible for the oxidizer to be drained from missile tanks overboard a submarine in case an emergency situation with a missile arises;

-- providing monitoring of the maximum permissible pressure in missile tanks during pressurization in case an emergency situation arises;

-- emergency cutoff of the engine in case it does not start up within the prescribed time after the command to start it has been issued.

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Among the technological measures for ensuring the safety of sea-based liquid-propellant missiles are the following:

-- monitoring of the air-tightness of missile tanks and fittings in the manufacturing stage with the use of highly sensitive testing methods (up to $1 \cdot 10^{-4} \frac{l \cdot mm\ Hg}{sec}$). (After filling, the oxidizer tanks are tested again for air-tightness by keeping the article in a "fog chamber" for five days. The absence of swelling of the paint and varnish coating confirms that the tanks are air-tight);

-- extensive application of automatic welding with x-ray monitoring of the welds. (Recently electron-beam welding has begun to be introduced. This contributes to enhancing the quality of welded joints and thereby raises the air-tightness level of the joints);

-- experimental development of a missile structure /to enhance/ its durability under conditions of intense exposure to increased humidity, propellant component vapors, and sea water;

-- ultrasonic monitoring /to confirm/ the absence of internal defects of a metallurgical nature in forged pieces to be used in the manufacture of essential and other parts.

Organizational-operational solutions are directed above all at ensuring the safe operation of a missile during its storage in a submarine launch tube as well as during the performance of prelaunch preparation. Of these solutions, the following should be included among the basic ones:

-- monitoring, with the aid of gas-analysis sensors, of the composition of the gas medium in submarine launch tubes containing missiles;

-- monitoring of the elevation in temperature in a launch tube above the maximum operating temperature (such an elevation in temperature can occur as a result of the interaction of components with each other or with water vapors in the event of loss of air-tightness by missile tanks);

-- providing water injection (spraying) in the circular clearance between the missile and launch tube walls in the event of component leakage into the launch tube;

-- limiting to no more than three months the storage of a deampulized missile in a submarine launch tube;

-- providing automated prelaunch missile preparation, which aids in eliminating the effect of human errors on the safety of prelaunch missile preparation;

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Starting in 1970, the Design Bureau of Machine Building has been engaged continuously in programs to investigate questions of the use of new liquid propellants in naval missiles. These are the initial concept /avanproyekt/ for development of materials /design data/ for the D-9M complex (Figure 2) and the KRISTALL /Crystal/, MALAKHIT /Malachite/, TOPAZ-2, and IZUMRUD /Emerald/ scientific research programs. These programs have made it possible to determine a list of components that are most acceptable for naval missiles and most workable as far as practical application is concerned.

It should be noted that, together with the standard oxidizer AT, VPV -- highly concentrated hydrogen peroxide -- may be regarded in the future as a prospective oxidizer mainly because of its low toxicity. Among the fuels for consideration in experimental-design work, lyuminal-A and low-toxic tsiklin are the most suitable. Of the components enumerated, the pair AT + lyuminal-A provides the greatest energy effect. In terms of utilization properties, a propellant based on lyuminal-A is the closest to the standard propellant. Therefore, there is every reason to assert that the continuity in the technical solutions which ensure safety and reliability and which have been developed for missiles using standard propellant will facilitate introducing the propellant AT + lyuminal-A in prospective naval complexes (Table 3).

The design studies of the Design Bureau of Machine Building related to naval complexes show the following:

1. Taking as a guide the current level of performance achieved in full-scale chambers operating on lyuminal-A (with the presence of the third component UDMH in amounts of 2.5-3 percent of the total propellant weight, and a relatively moderate pressure level in the combustion chambers [100-150 atm]), the use of propellant AT + lyuminal-A will yield an increase in missile flight range of approximately 25 percent as compared to standard propellant if missile dimensions remain fixed.

2. The achievement of a higher pressure level of up to 200-300 atm in the combustion chambers of lower stages will make it possible to increase range up to approximately 32 percent.

3. Discontinuing the use of the third component in the future, along with achieving chamber pressures of 200-300 atm, will yield an increase in range of up to approximately 40 percent.

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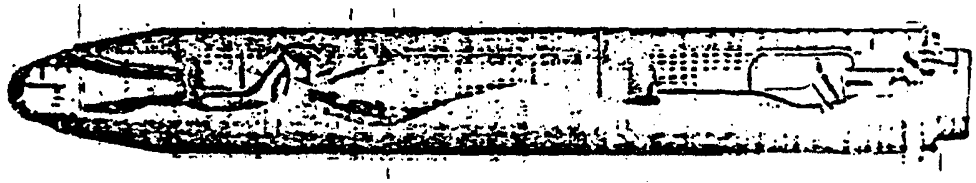
THE R-29D MISSILE



Maximum firing range, km*		
Firing accuracy:	For 90% of the missiles	For 10% of the missiles
— range, km*		
— direction, km*		
Warhead		A118
Weight of fueled missile, t		33.2
Propellant		AT + UDMH
Thrust of engines:		
— I stage on the ground, t		65.5
— II stage in a vacuum, t		13.5
Time to prepare missile for firing, min		6-8
Interval between launches of missiles in a salvo, sec		7-20
Launch conditions:		
— sea state, balls		up to 8
— submarine speed, knots		5
— launch depth, m		40-50
Number of missiles on submarine		12-16
Dimensions of launch tube:		
— height, m		14
— diameter, m		2.1

Figure 2

*Translator's note: No data are provided for this entry.

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Table 3

FUNDAMENTAL ASPECTS OF THE APPLICATION OF LIQUID PROPELLANTS IN NAVAL MISSILES

Aspect of Application	Characteristic Features of Missile Complexes
Energy characteristics	A class of missiles has been developed that, in terms of performance, is on a level with or surpasses foreign counterparts at a time when we are lagging behind with respect to the size-weight characteristics of warhead materials and control systems.
Operating characteristics of a missile complex resulting from the use of liquid propellant	Monitoring of the composition of the gas medium in submarine launch tubes; monitoring of the elevation in temperature in a launch tube above the maximum operating temperature; emergency draining of the oxidizer; injection of water in the circular clearance of a launch tube in emergency situations; spraying of missile and injection of water in a launch tube in emergency situations.
Effect on the technical configuration of a missile and complex	High configuration compactness for a missile and in a submarine launch tube; "burying" of missile engines in the component tanks and elimination of the interstage compartments; double-layered divider end plates; launch by means of I stage sustainer engine; emergency cutoff of I stage engine.
States of raw material and industrial resources	Production of the inexpensive propellant AT + UDMH has been refined; more than 15 years of utilization of the same type of propellant for sea-based missiles.
Prospects for improving engines using the given propellant	An increase of 11-13 sec in specific impulse for the propellant AT + UDMH by increasing the combustion chamber pressure; a decrease in relative engine weight through the use of titanium alloys in construction.

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Table 3 (cont)

Aspect of Application	Characteristic Features of Missile Complexes
Prospects for replacing the given propellant with new types of propellants	Utilization of the pair AT + lyuminal in the next prospective naval complexes; an increase of 25-40 percent in the efficiency of the propellant over that of the standard propellant.
Comparison of the forecast of the development of specifications for prospective weapons complexes with prospects for the development and use of new propellants	The Navy specifications established for the prospective D-35 complex within the framework of the GORIZONT 4R /Horizon 4R/ scientific-research program can be fully satisfied only if liquid propellant AT + lyuminal-A is used.
Consideration of the factor of competition in tactical-technical characteristics /compared to/ foreign complexes, above all, US missile complexes	In considering future possibilities for 1980-1990, superiority over foreign counterparts of the Trident 2 type with respect to tactical-technical characteristics can be achieved, with other conditions being equal, only if liquid propellant AT + lyuminal-A is used.

The use of propellant AT + lyuminal in prospective sea-based complexes will make it possible to satisfy the increased requirements as to their tactical-technical characteristics and to achieve considerable superiority over prospective foreign complexes having an analogous purpose.

In our opinion, the work of introducing lyuminal-A into sea-based missile complexes should be one of the most important tasks for the next few years.

The propellant VPV + tsiklin is considerably less efficient than a propellant based on lyuminal. If VPV + tsiklin is used, the increase in range amounts to approximately 10 percent in relation to /that produced by/ the standard propellant. The pair VPV + tsiklin is attractive because of its low toxicity level as compared to the pairs AT + UDMH and AT + lyuminal-A. Therefore, it is advisable to consider VPV + tsiklin for use in sea-based complexes in the future, especially if there are possibilities for providing the required tactical-technical characteristics of complexes through increased missile dimensions.

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In our opinion, the basic questions that must be resolved regarding this pair are:

-- increasing the stability of highly concentrated hydrogen peroxide to a level no lower than 0.1 percent /decomposition/ per year during storage in /missile/ tanks made of AMg-6;

-- ensuring fire and explosion safety for a VPV-loaded missile in all stages of operation;

-- decreasing the cost of tsiklin.

We have recently been assigned tasks requiring the development of special propulsion systems of a new type for MIRVed nose cones and guided warheads /boyevyye bloki/. The engine units of this class are /to be/ characterized by:

-- multiple thrust modes with a tenfold or higher depth of thrust control;

-- a prolonged operating time of up to 3000 sec;

-- multiple ignition and a pulsed operating mode;

-- /the capability to/ operate under conditions of increased axial and lateral g-loads up to approximately 100 g;

-- /the capability to withstand/ exposure to the destructive elements of a nuclear burst.

In the future, we will combine this most important direction of work with the utilization of a liquid monopropellant -- hydrazine; however, a wide range of investigations has to be organized and carried out. Questions pertaining to the use in sea-based complexes of other high-energy propellant combinations based on fuels containing boron and beryllium are being studied by us as a more distant prospect and, in our opinion, have to be investigated rather fully within the framework of the long-term programs of scientific-research organizations.

It is essential to pay attention to the following circumstance. In the practice of developing new liquid rocket propellants, an appreciable gap has developed between the pace of the search for new formulas and that of the investigation of "engine" processes and the operating "missile" characteristics of components. As a result, the practical application of new highly efficient liquid propellants is being retarded. The work on lyuminal is an example of this.

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