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A.S. Okhotin

The presence of such properties in outer space as weightlessness and a high vacuum opens great possibilities for a new field of science and technology, space technology. Inasmuch as simultaneous and long term modelling of such properties is impossible in terrestrial conditions, their realization is only possible in conditions of long term space flight. The basic technological processes in space are determined by the principles of behavior of substances in conditions of weightlessness and a deep vacuum and for a number of processes, only in weightlessness. Therefore, the immediate problem for researchers of the processes of space technology is the study of characteristics of a whole series of physical and chemical phenomena in conditions of weightlessness. Some of these phenomena are diffusion, surface tension, heat exchange, crystallization and others. /3*

We will consider briefly how these phenomena occur differently in weightlessness. With the absence of external forces (in particular gravity), the mechanical behavior of a fluid is determined only by the interaction of the surface tension force which plays the role of the forming force and the force of intermolecular adhesion (viscosity) which resists this deformation. The surface tension layer in this case can be considered as an elastic shell which affects the behavior of the body in such a way that a state of equilibrium of existing forces is achieved. The latter occurs in the case of an ideal sphere. Consequently, in weightlessness, any fluid in a free volume strives toward a spherical shape if external

*Numbers in the margin indicate pagination in the foreign text.

perturbation is absent.

Calculations show that the average rate of deformation in the absence of external forces equals /4

$$\frac{dv}{dx} = \frac{b}{\mu} \left[\frac{\text{cm}}{\text{s}}\right],$$

where v--is the rate of deformation at a distance x,

b--is the coefficient of surface tension,

μ--is the coefficient of viscosity.

We will illustrate this relationship with the following example [1]. It is well known that viscosity of melted metals is close to the value of viscosity of water and surface tension in liquid metals is 10--20 times larger than in water. The deformation rate in metals is on the order of $3.7 \cdot 10^4$ cm/s, and in water it is $0.7 \cdot 10^4$ cm/s. All of this results in the fact that melted metals in weightlessness can acquire a spherical shape in a very short period of time. Thus, iron cast from a container with diameter 30 cm and length 30 cm takes on the shape of a sphere after 2 microseconds. Inasmuch as the absolute values of internal forces affecting the material are small, any external perturbations easily deform the fluid. Most often, such forces are oscillation of the surface under the effect of acceleration. It is necessary to take into account (when analyzing other phenomena) that on board any spacecraft, it is practically impossible to obtain a complete absence of gravitational force and it is necessary to talk about a force of gravity close to zero. In this case, if an object is located at the center of mass of the spacecraft, this value amounts to $10^{-6}g$ (taking into account the force of attraction between the Earth and the spacecraft); if it is located outside the center of the mass, then the value of the gravitational force increases to $10^{-3}g$. Moreover, stabilization of the spacecraft necessary for normal functioning causes "bumps" which result in an irregular change in the force [word illegible in the original].

The work will be somewhat different with the effect on the /5 surface tension force if the body is found in a container with linear dimensions L. In this case, it is necessary to compare the force of surface tension bL with forces of inertia affecting the fluid equal to $ng\rho L^3$ (n--is the load factor, g--is acceleration due to gravity, ρ--is density). The ratio of these forces is the measure of the effect of the force of surface tension and is called the Bond criterion

$$Bo = \frac{b}{\rho n g L^2} .$$

Calculations of the contact angle showed that it does not depend on the value of the force of gravity and, consequently, depending on this angle, it is possible to determine the shape which the fluid in a container will take. An example of such shapes for fluid found in a spherical container is given in Figure 1.

In a whole series of technological processes, firstly those like the behavior of chemical reactions in gases or processes of synthesis of a melt in liquid metals, it is important to know the processes of diffusion and be able to control them. The processes of diffusion [2] are described by the well known Fick's law which in a unidimensional case has the form:

$$j_x = -D_{AB}\frac{d\rho A}{dx}$$

where j_x--is diffusion flow, D_{AB}--is the coefficient of diffusion of substances A and B, ρ_A--is density of the A substance on section dx. In such a description, the principle of diffusion clearly does not depend on the force of gravity, however the coefficient of diffusion D_{AB} is a function of temperature, pressure and composition and its value in weightlessness must be different from that in Earth conditions. Unfortunately, we have not yet studied in detail the values of the coefficients of diffusion in weightlessness and this is one of the most immediate research tasks in the field of space technology; but /6 undoubtedly it is true that the absence of the force of gravity makes it possible to obtain "ideal" values of D_{AB}. One should also say that Fick's law is based on a simplified model of the process of diffusion. In the work itself, the processes of diffusion depend on a whole series of factors and diffusion flow in a general form is a total of the members which describe ordinary concentrated diffusion jx, diffusion due to pressure jp, force diffusion jg and thermal diffusion j [illigible in original] $j = jx + jp + jg + jT$. In this case, we are interested in force diffusion which is expressed as

$$j_g = -\frac{C^2}{\rho RT}\sum_{j=1}^{n} M_i M_j D'_{ij}\left[x_j M_j \left(g_i - \sum_{k=1} \frac{\rho_k}{\rho} g_k\right)\right],$$

where C--is molar density of the solution, R--is the gas constant, Mi--is the molecular weight of the i component, Mj--is the molecular weight of the j component, Dij--is the coefficient of diffusion, xj--is the molar portion of the j component, $gigk$ is external effect of the i and k component, ρk--is its density, 11 is the number of components participating in the process. As is apparent, if the only external force is the force of gravity, then the value gi for all components is uniform and the value if $jg = 0$. In weightlessness, when applying any kind of external effects determined by the process on the system, the value jg will play its own role and change the course of diffusion processes in comparison with the conditions on Earth. It is particularly important that diffusion in weightlessness can occur in substances which can hardly be confused in Earth conditions. And this makes it possible to obtain almost new unique substances in weightlessness.

The distinctive factor in the course of processes of heat /7 transfer in substances found in outer space are also involved with the absence of the force of gravity and relate to the process of convection fluids and gases. From an analysis of the processes of heat transfer during natural convection [3], it is well known that their occurrence is different in unlimited space or a close volume. A study was made with different bodies and different fluids to study the intensity of heat exchange in conditions of free motion. As a result of generalization of these works, criteria of the relationships were obtained for the mean values of the coefficient of heat transfer, which in a general form, can be presented as

$$Nu = A(Gr \cdot Pr)^B$$

where $Nu = \frac{\alpha l}{r}$ --is the Nusselt criterion, α--is the coefficient of heat exchange, l--is the geometrical dimension, λ--is heat conductivity, $Gr = g\beta\Delta t l^3/v^2$--is the Grasgof criterion, β--is the coefficient of volumetric expansion, Δt--is temperature gradient, v--is kinematic viscosity, $Pr = {}^{v}/a$--is Prandtl's criterion, α--is the coefficient of temperature conductivity. The values A and B are numerical coefficients depending on the shape of the body and the rate of occurrence of the process. In a case where the process of natural convection occurs, it is assumed to be considered as an elementary phenomenon of heat conductivity introducing the concept of the equivalent coefficient of heat conductivity $\lambda_{ek} = Qb/F\Delta t$, where Q--is thermal flow, b--is the dimension of enclosed space, F--is surface heat exchange. If heat conductivity of the substance is designated by λ, then one introduces the dimensionless value $E_k = \frac{\lambda_{ek}}{\lambda}$, which characterizes the effect of convection and is called the coefficient of convection. It is pointed out that

$$E_k = F(Gr \cdot Pr)$$

It is fully obvious that inasmuch as the determining parameter in the Grasgof criterion introduces the force of /8 gravity "g", the coefficients of heat exchange, and consequently processes of natural convection and weightlessness will be insignificant. Namely, such a "quiet" behavior of fluid and gases in weightlessness makes it possible for us to predict the possibility of obtaining materials in space which are more perfect in structure.

One should not however think that the presence of weightlessness excludes thermal convection completely. For this it is necessary to provide a whole series of conditions many of which we still do not fully understand. The point is that actual technological processes, such for example, as the course of chemical reactions for crystallization of alloys of metals, occur at a minimum in two phase (and often in multiphase) media. Even obtaining any kind of high purity substance (for example, germanium monocrystal) must be done in a closed volume in which one always will have gas "bubbles" that is, it will be a two phase medium. Inasmuch as the behavior of almost all technological processes involves application of temperature or pressure gradients on the substance, under the effect of external forces, the components of the medium will behave differently. The occurrence of mass transfer of one of the components is possible, for example, of a gas bubble in the case of germanium which results in the appearance of temperature gradients on the boundary of the phase and in thermal stream convection. To evaluate the quantitative value of the coefficient of convection and find a method of controlling this process for different substances and conditions in weightlessness, is one of the leading problems which must be solved in space technology.

Here, one should particularly study the processes of heat and mass transfer in the capillaries in weightlessness [4]. /9
The interest in this process is explained by the fact that from an analysis of the phenomena in capillaries it is clear that in

weightlessness they must be sharply increased; this can be used in different technological processes. As was determined analytically and supported experimentally, the rate of rise in the fluid of the capillaries is

$$V = \frac{dl}{d\tau} = \frac{2br^2\cos\theta}{0.2r^2\cos\theta+8\mu lr},$$

where l--is the length of the column of fluid, τ--is the rise time, r--is the radius of the capillary, θ--is the contact angle. From an analysis of this relationship it follows that $(l_{max})_{g=0} = \infty$. It is difficult to judge the actual value of maximum rise of the fluid in a capillary because of the absence of a large amount of experimental data.

The processes of mass crystallization and growth of monocrystals in an ideal state must occur identically in conditions of space and Earth. However, inasmuch as in actual circumstances their occurrence, to a significant degree, is determined by thermal and mechanical procedures, and all of the above listed characteristics of a transfer phenomenon in the broad sense of their understanding, in conditions of weightlessness are the subjects of the main questions which determine the final result. Right now it is necessary to point out that a study of the processes of crystallization in weightlessness has only begun and therefore the expressions presented above in their realization have a qualitative character and are written basically for an "Earth" test. It is obvious therefore that the methods of crystallization of materials on spacecraft are the same as those used in terrestrial conditions.

Probably, the basic requirements for the process of crystallization in weightlessness can be considered to be obtaining uniform materials improved in structure and in the case of the presence of admixtures, distribution according to the prescribed law. Here, it is important also to establish what conditions of crystallization in weightlessness make it /10 possible to approach the natural limit which is determined by statistical distribution, principles of distribution of phases or admixtures in the crystal.

Thus, Figure 2 shows crystals of Seignette's salt obtained in terrestrial (a) and space (b) conditions. Photographs obtained with a uniform increase visually show how large crystals which form in weightlessness conditions are. Curves which indicate distribution of gallium admixtures in germanium are characteristic (Figure 3). On the graph, it is clearly apparent how large the uniformity of distribution of the admixture is along the length of the ingot which is achieved in weightlessness conditions. Basic imperfections affecting the properties of the crystal occur in them in the crystallization process. This process is very sensitive to very insignificant changes in external conditions such as, for example, the heat field of the units. There is no strict mathematical theory which makes it possible to quantitatively describe all of the characteristics of the crystallization processes and therefore we will describe quantitatively their basic characteristics which lead to imperfection. At the present time, the theory determines two basic types of imperfections.

The first involve variations in temperature in the unit, disturbance of the rate of growth (in the case of obtaining monocrystals), vibration of the units, etc. These deviations from an ideal system of the process can be kept to a minimum in weightlessness conditions. The second type of imperfection of the crystal involves the regular changes of its composition in the process of hardening. These principles are determined by the laws of phase transformations, encompass the whole volume of the solid phase and are called segregation disturbances /11 of constancy of the composition. Methods of eliminating these disturbances consist of creating conditions which provide establishing equilibrium within a solid phase during its growth.

The first of these approaches consists of long term annealing of the growing layers of the solid phase which naturally results in such a slow occurrence of the crystallization process that its realization becomes practically impossible.

The second approach consists of a disturbance in conditions which provide equilibrium outside the solid phase so that the system becomes fully uniform. Creation of a nonuniform melt, naturally, desirably is obtained with an absence of mixing mechanisms, that is, a purely diffusion method. However, as analysis has shown, this is proctically impossible for most materials and the only method of creating a nonuniform melt consists in its convective mixing. This method which is practically complex in Earth conditions is considered to have a good future in weightlessness. The point is that it involves an increase in the rate of growth required for decreasing loss on the initial imperfection of the crystal which can be achieved only due to an increase in temperature in the system. In terrestrial conditions, this results in a sharp increase in convective transfer and imperfection in the crystal, but in conditions of weightlessness, it can only strongly distort the thermal procedure of the unit and make it possible to obtain fairly uniform crystals. A modification of the second method is diffusionless crystallization possible only at high rates of growth which is impossible to accomplish for many materials due to their physical and chemical properties.

Inasmuch as obtaining alloys of mass crystallization does /12 not require special methods and units and can be realized in ordinary heating devices, we will consider only methods for obtaining monocrystals. This involves the fact that the most promising in space technology in recent years are problems involved with obtaining semiconductor monocrystals with high purity and perfection. As has already been noted above, today, when space technology is in the initial stages of its development, its methods essentially repeat widely known terrestrial methods.

This is how the work of obtaining monocrystals goes. One of the most widespread methods is the Bridgman method whose system is given in Figure 4. In this method, the material with monocrystalline seeding (1) is placed in a special ampoule (2). The process of growth of monocrystals itself can be limited be two methods. The first of these consists of fact that the ampoule is placed in front of (3) constructed so that all of the material in the ampoule is melted except for the seeding which is in cooling zone (4). Then, at the prescribed rate, the ampoule passes through the cold zone; as a result of this a monocrystal substance is obtained. This method has a positive aspect in that constancy in the rate of growth and temperature gradient in a crystallization zone are realized. A disadvantage is the presence of vibration due to the mechanism for moving the ampoule. The separate method for growth of the crystal according to the Bridgman method consists of placing the ampoules with the seeding in a furnace in whose heating zone a temperature gradient has already been created. Its position is established in such a way that seeding is at a temperature lower than a melting temperature and the remaining material is in a liquid phase.

Crystal growth in this case occurs by movement along the ampoule of the temperature gradient due to cooling. Advantages of this method include the absence of external perturbations of the vibration type and the disadvantage is the practical impossibility of maintaining a constant temperature gradient which results in certain imperfections in the crystals. /13

One of the most widespread methods in terrestrial conditions for obtaining monocrystals is the Chokhral'skiy method. It involves uniform rise in seeding and, consequently, due to the force of surface tension, of part of the material melt. Because the lift device intensely withdraws heat, in the rise process, crystallization of the material occurs. This method is exemplary for materials with low vapor pressure over the melt and contains a number of disadvantages including mechanical external effects on the growth process and complexity in maintaining a constant temperature procedure. Its advantage is providing a constant rate of growth, the possibility of drawing the crystal to a large diameter and simultaneous purification of the material. Due to the presence of a large free surface, this method is not yet being carried out in space technology; however, its modification (Stepanov method) is very promising for conditions of weightlessness. A diagram of this method is given in Figure 5. Here, the melted material (1) is fed into the crystallization zone (2) through capillary apertures (3) of practically any shape (this method is widely used particularly for obtaining shaped crystals). On the output from the capillary aperture, the melt "meets" the seeding and then is extended similarly to the Chokhral'skiy method using the lift device. Taking into account the characteristics of behavior of the substance in capillaries, about which we have spoken above, one can expect to obtain monocrystals by this method in a weightless state with a high growth rate.

This gives the basis for considering the realization and diffusionless crystallization in weightlessness as one of the effective methods of combating segregation imperfection. /14

Undoubtedly, the development of space technology results in the appearance of new methods for obtaining monocrystals distinguished from those realized on Earth. In truth, one of the first of these methods will be a modified method of crucibleless band melting whose realization on Earth is possible only for materials with a large coefficient of surface tension and small dimensions. In weightlessness, the same method is suitable for practically any materials and the characteristics of its design shaping must only be considered inertia forces which will always exist on space equipment in the form of a pulse (for stabilization of the spacecraft) or constantly acting.

In this case, obviously, a crucibleless melt in weightlessness can advantageously be carried out in conditions of a magnetic or electrical field. A diagram of the equipment for melting metals in a magnetic field is given in Figure 6. Here, sample with spherical shape (1) is maintained in weightlessness and protected from inertia effects by the magnetic field (2). It is necessary only in this method always to take into account that the magnetic (or electrical) field is the source of the external effect and can lead, for example, to a convection process in the material.

Obviously, a detailed development of the equipment for a crucibleless melting in weightlessness must provide the optimum conditions for a minimum possible breakdown during operation of the crystal. Going from what has been said, the equipment for obtaining different substances on spacecraft is advantageously manufactured and combined either in the form of individual instruments or in the form of special production sections.

The former are advantageous when obtaining any kind of an /15
actual group of materials in a small quantity is necessary for research purposes. For example, (Figure 7), a furnace for obtaining semiconductor monocrystals by the Bridgman method can be made in a small volume equipped with a regulating block and mounted practically in any location on the spacecraft. The actual conditions of its grouping is convenience in access and conduct of technological operations. Also, equipment can be made for studying conduct of welding and cutting processes with an electronoplasma beam (Figure 8). Here, the source, for example, an electron beam is mounted in a special chamber so it can be pointed in any direction. The table to which the sample is attached is equipped with a rotating device which makes it possible to carry out the welding process either manually or automatically.

When a whole complex of technological operations is being carried out which involves using different substances in weightlessness and a possible analysis of the basic characteristics of the materials obtained, it is necessary to create special space laboratories in the form of sections or modules (Figure 9) joined with the spacecraft and consisting of a set of units and equipment for controlling them. It is obvious that in this case, the efforts of a group of operators are required for carrying out a large volume of technological operations and the section must be designed taking into account convenience for their simultaneous work.

Operation of a such a technological module, and in the future, for providing space production on a large scale, presents a new problem to the creators of spacecraft: providing the required power for all of the technical equipment.

The point is that at the present time spacecraft have power /16 on the order of several kilowatts which is completely adequate for carrying out experimental and test and industrial technological operations. When there is talk of special spacecraft factories, then the power required is tens and hundreds of kilowatts which is impossible to provide with solar photobatteries or chemical sources of current. For this purpose, the most promising are nuclear energy space units whose development now is being carried out intensely throughout the world. Putting together such a reactor (1) in a spacecraft is shown in Figure 10. Creation of reactors and transformers on thermal electric or thermoemission generators are the most advantageous. The first can operate with a power up to 10--20 kW, the second up to 100 kW. A machineless method of transformation of such devices is important for technical operations because the presence of external vibration effects on the spacecraft as a whole is excluded and, consequently, on the technical equipment as well which could occur if the power unit operated according to the reactor turbine system.

This article does not intend to give a detailed examination of the characteristics of operation of such power devices and their characteristics. These questions are discussed in detail in specialized literature and are generalized and presented in the review in reference [5]. It is only necessary to note that the presence of a reactor on board a spacecraft always creates the possibility for radioactive radiation even of small intensity (with a special biological protection) which creates a number of special difficulties in the work and operation of these space technological stations. Therefore, research is being carried out for other sources of power to provide the levels indicated above.

Among the most promising is the use of solar energy directly /17 in the technological instruments. The creation of high temperature in terrestrial solar furnaces has recently occupied researchers and significant progress has been made at the present time in this field. Development of solar furnaces is being carried out for space purposes [6]. The principle of their operation is based on concentration of the incident light flux using special mirror concentrators with a single focal spot. Solar furnaces can be divided into the following categories according to the principle of concentration (Figure 11): paraboloid (1), paraboloid cylindrical (2) and facet (3). The degree of concentration in them depends on the precision of the concentrator and the coefficient of reflection of its mirror coating and consists theoretically for the first, approximately 1000, for the second, approximately 100 and for the third, from 10--200. The concentrators with spherical and conical surfaces are the least effective.

The characteristic feature of all solar concentrators is nonuniformity of heat flux on the focal spot (Figure 12). This is most clearly expressed in a paraboloid concentrator (1), which makes it possible to obtain temperatures up to 3500° C in its focus in space. The largest uniformity of power in the focus can be created in facet concentrators (2), although the level of energy in this case will not be high and in temperatures above 1000° C can hardly be achieved in this case. The advantage of solar concentrators is the possibility of supplying them in a complex or separated form in orbit and scattering here of surfaces with fairly large dimensions (up to 100 m^2). But if one considers that in space on Earth orbits, the solar flux is on the order of $1300 \frac{kcal}{m^2 hr}$, then it is completely practical taking into account the entire loss to have solar furnaces with a power at the focus of 100 kW.

Of course, the nonuniformity indicated above in distribution /18 of energy in the focus requires development of special technological instruments and also operation of these devices suitable for the cosmonaut in open space but all these problems although complex are mainly solved and undoubtedly the creation of solar furnaces for space technology will be successfully developed. It is necessary to say further that carrying out long term production processes, in this case, requires putting the spacecraft into a heliocentric orbit. An examplary system for arranging the solar furnace (1) on the spacecraft is shown in Figure 13. Here, solar photobatteries (2) serve as the source of electrical energy for the life support system and for operation of instruments for control of technological processes and the properties of the materials obtained. The solar concentrator is the source of thermal energy for a universal space technological instrument.

All that has been mentioned above makes it possible to determine the basic approaches to space technology, including scientific and research and test and industrial work in obtaining different materials and carrying out a number of technological operations.

An analysis of the prospects for space technology makes it possible to note two basic approaches for its development. The first involves the creation and operation of large long term space stations. They will be necessary even in coming years for solving problems involving the study of natural resources on Earth, environmental protection, geodesic, astronomical and other works important for the national economy. The creation of stations with weight of hundreds of tons and crews made up of tens of persons is planned for these purposes. Their creation is done most economically by recovery in orbit of separate sections and their subsequent assembly in space conditions.

For organization of assembly in space it will be necessary to use such technological operations as welding, soldering and jointing. The long term operation of such stations requires a specially organized operational service involving prophylactic and repair operations. For complex solution of this aspect of space technology, it is necessary to study all of the features of the operations indicated in conditions of weightlessness and a deep vacuum taking into account the long term effect of variation in temperature and space radiation flux. The best technological systems were selected on the basis of this study including methods of carrying out operations, special technological equipment and specialization of the cosmonaut operator. The beginning of the work, the first in the world, was an experiment in welding and cutting metals using an electron arc method, methods using a floating electrode and plasma arc on the Soyuz-6 spacecraft in October, 1969. /19

Cold diffusion vacuum welding, welding using an optical quantum generator, electric contact and ultrasonic point and roller seam welding and welding with an electromagnetic field are some of the promising methods for welding in space. Also, methods of welding with a concentrated solar beam are being studied. For determining the optimum method of welding when carrying out any kind of actual operation in space, it is necessary to thoroughly study the features of the course of these processes in conditions of weightlessness in a deep vacuum. This particularly applies to a method involving melted metal. A number of complex problems must be solved when developing and creating special welding equipment. For example, welding operations on the Soyuz-6 and flying laboratories for such materials as 1Kh18N9T stainless steel AM6 aluminum alloy, VTI and OT4 titanium alloys with thickness of the sheet 1, 5-2 mm indicated that they are reliably welded without the formation of a through crater in the liquid metal bath. /20

At the Institute of Electric Welding im. Ye. O. Paton, a number of studies were made in order to develop processes and create maneuverable, highly reliable and failure free equipment for electron arc welding of thin sheet materials in a state of weightlessness. As a result of this work, the Vulcan unit was created which is a space automatic device which makes it possible to weld with an electron beam, plasma arc and floating electrode. Welding operations on the Soyuz-6 and flying laboratories were carried out using this unit and it was found that the structure of the welded seams and the areas near the seam were practically the same as when welding on Earth. It must be noted that the use in space of the Vulkan type unit can be desirable not only when welding but also when cutting metals, processing parts, and obtaining particularly pure materials.

An important problem in space technology is providing operation and repair work for special equipment and instruments which make it possible to carry out these operations in conditions of weightlessness with high productivity. The second approach to space technology involves obtaining materials and articles in space whose production under terrestrial conditions is difficult or completely impossible. This aspect of space technology is based primarily, on such unique conditions of outer space as weightlessness and a high vacuum, and the prospects for its development are determined by a significant (up to 10 times) decrease in the cost of delivering loads from space even in the near future. Production in space materials and articles which cannot be obtained on Earth generally do not consider the question of their cost in view of the unique character of the results. Among possible types of materials whose production is desirable in space conditions, we can name the following:

First, there is a combination of metals, metals with oxide of /21 metals, ceramics or glass of sample compounds, organic compounds which cannot be mixed in terrestrial conditions but can be mixed in a state of weightlessness. It is proposed that a number of these materials will have singular structures, electrophysical and optical properties which make it possible to create mainly new types of instruments on their base in the first place for electron, radiotechnical, electrotechnical and medical industries. The possibility of mixing metals with gases makes it possible also to create high strength foam metals due to the uniform distribution of protected gas bubbles in the materials. For example, steel manufactured in space by this method with 87% gas and 13% intrinsic steel will have a specific weight of aluminum and the strength of steel and will facilitate considerable progress, for example in aircraft construction. Melting in weightlessness makes it possible to obtain glass without any kind of admixtures with higher optical properties than the glass from Earth production. Obtaining unique monocrystals in space with semiconductor properties having large dimensions and high purity makes it possible to considerably increase the effectiveness of a large number of electronic instruments. One can point to monocrystals of germanium selenide as an example with thickness 1 mm, width 4 mm and length 25 mm obtained in space; this exceeds the dimensions of these same monocrystals obtained in terrestrial conditions by several times. Monocrystals of indium antimonide obtained in space have a perfected structure which cannot be even approximately obtained on Earth. Growing acicular monocrystals with highest strength makes it possible to use them as singular housing and space constructions.

Thus, "needles" of sapphire obtained in space have a strength /22 of up to 2 tons per square millimeter which is ten times higher than the strength of same material obtained in terrestrial conditions. In space, it is possible to carry out a whole series of unique chemical processes, processes of fermentation and cultivation of bacteria with high purity in the product obtained. Obtaining ideal solid and hollow metal spheres in a weightlessness state makes it possible to create ball bearings with the best properties on their base. The capability of liquid bodies (including metal melts) in weightlessness to form strong spherical shapes makes it possible to obtain new materials without crucibles in a "pure" form and thus to exclude the interaction of the crucible with the material and to increase its purity. One should note that accomplishing these operations in the second approach to space technology requires much experimental testing of a whole series of questions inasmuch as most of them have not yet been studied. First of all, there is the study of the physical and chemical basis for the course of different technological processes and conditions of weightlessness and a deep vacuum. An important part of this question is the creation of methods for predicting the course of processing in space on the basis of data obtained in terrestrial conditions. Another important question needed in experimental testing is the study of new technological methods, optimum in space conditions, and the design and development of technical equipment for their realization. Finally, a detailed analysis of the properties of materials and articles obtained in space is necessary; this permits definitely establishing the approaches to space technology which must be developed and which can be used in the national economy.

Calculations made indicate that the successful development of space technology permits obtaining, by the year 2000, in space, materials and articles useful for needs on Earth with weight of hundreds of tons and cost of tens of billions of dollars; these include biological products (virus insecticides, bacteria and blood globlules) for a total of approximately 17 billion dollars (according to USA data). Of course, these needs, as space technology develops, which are only the first steps in the science, can be changed, but right now the prospects for this approach to space operations are obvious. /23

On the whole one can say that the development of space technology, as this field of science develops, leads in the near future to a closer connection between space studies and the needs of the national economy. In the next 10 years, we must begin to collect information on the development of this new branch of industry whose basis will be obtaining different materials and articles in space conditions with their delivery to Earth; this undoubtedly will facilitate the further progress of science and technology.

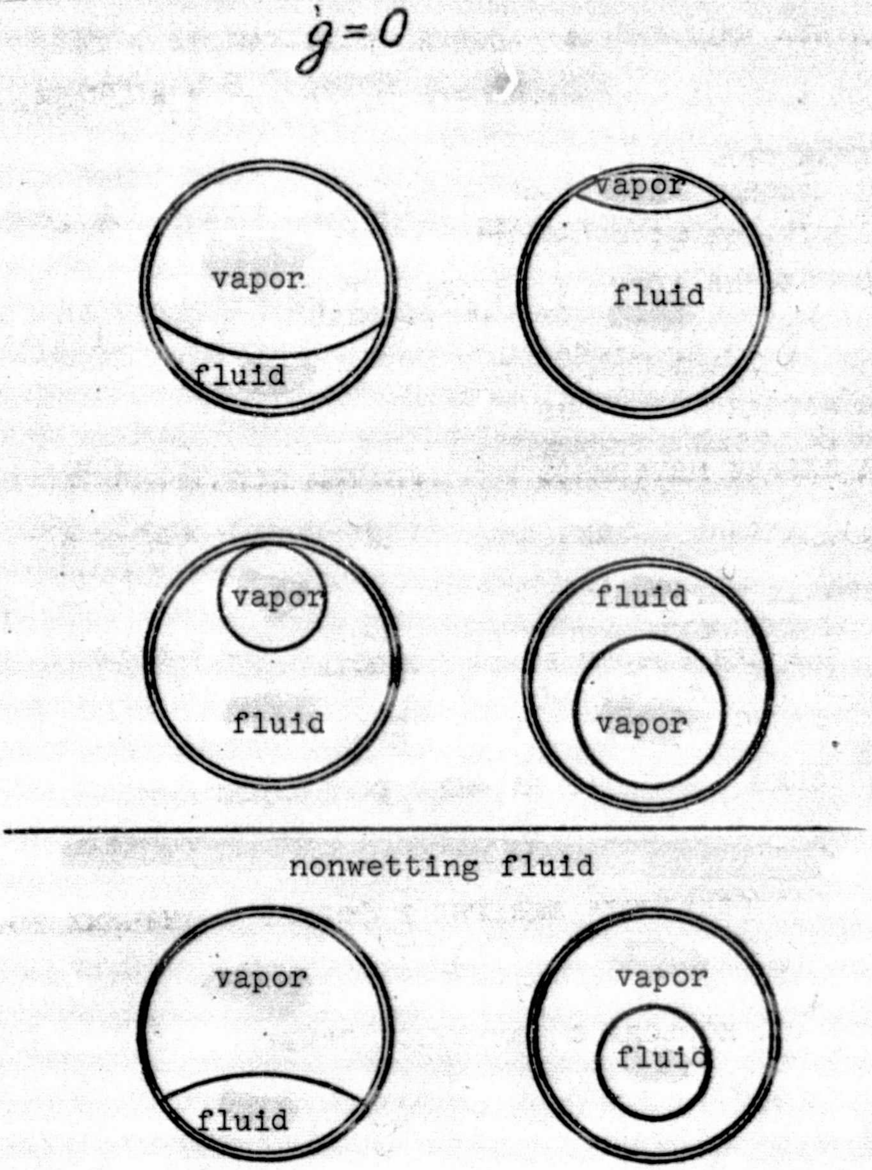

Figure 1. Behavior of fluid in conditions of weightlessness in spherical container 1, 2, 3, 4--wetting fluid, 5, 6--nonwetting fluid.

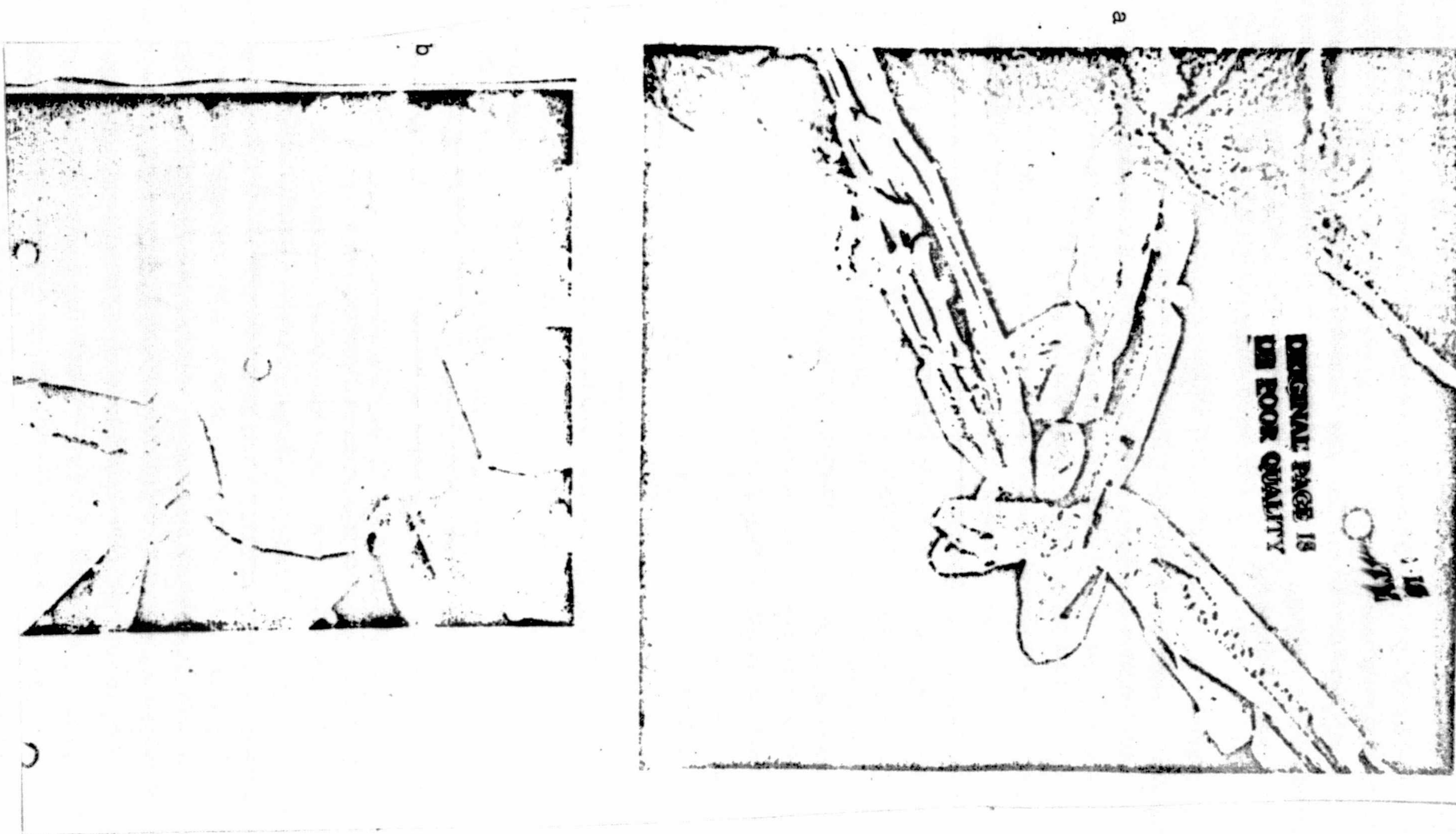

Figure 2. Crystals of Seignette's salt

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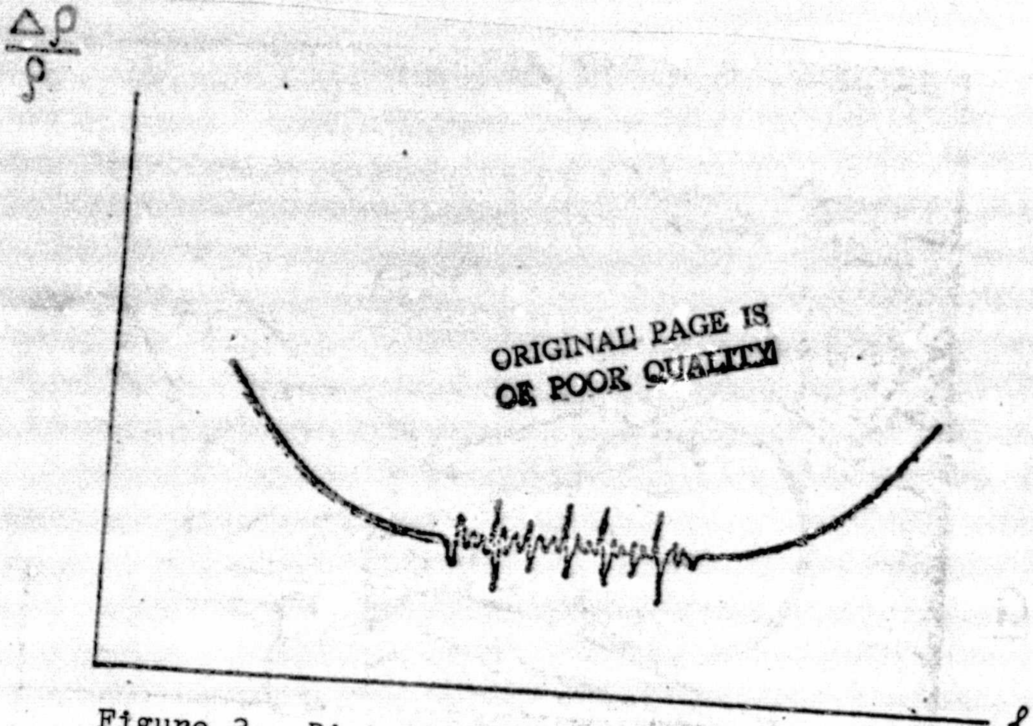

Figure 3. Distribution of admixtures of gallium in germanium.

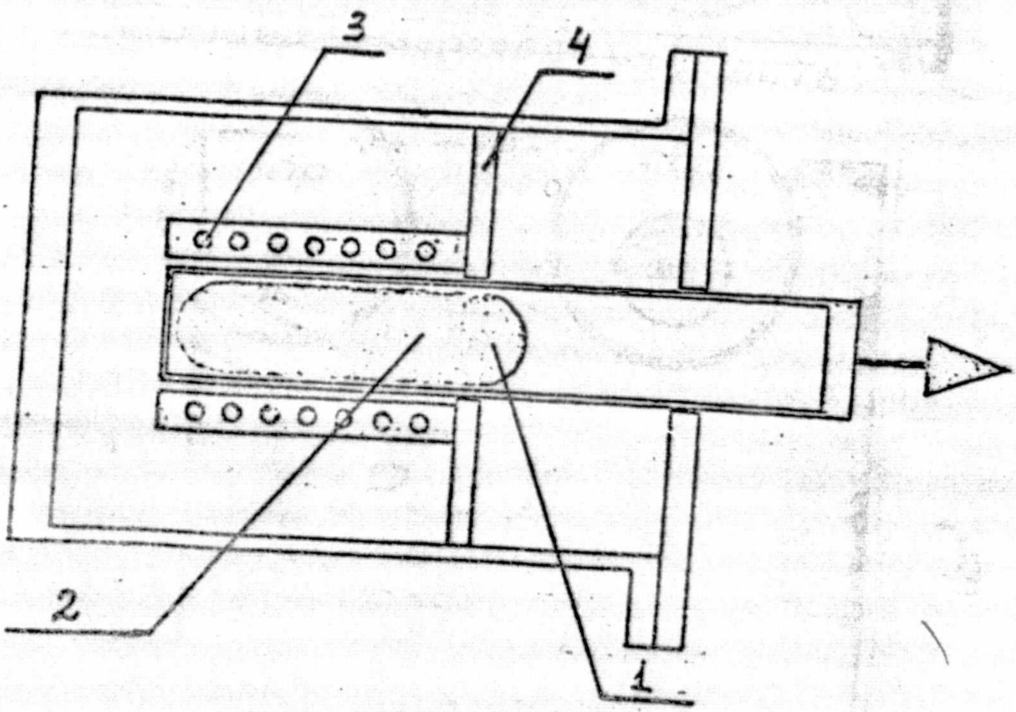

Figure 4. Diagram of the Bridgman method.

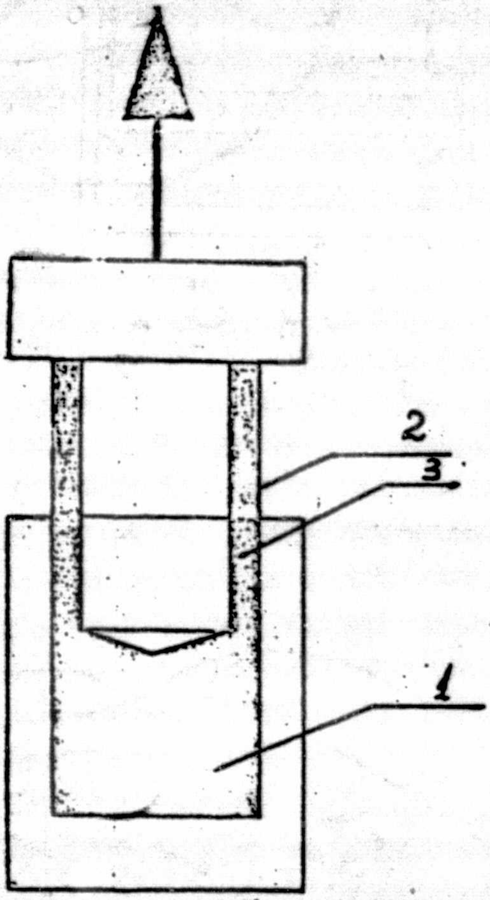

Figure 5. Diagram of the Stepanov method.

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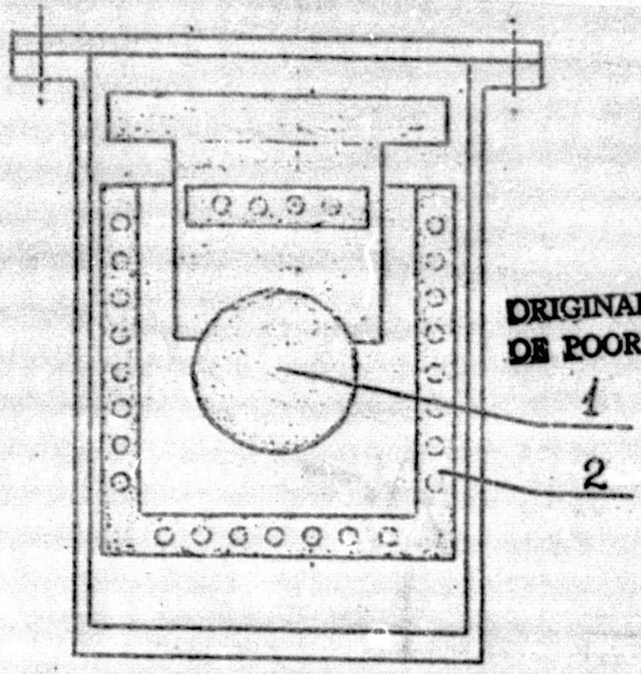

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Figure 6. Diagram of melting material in a magnetic field.

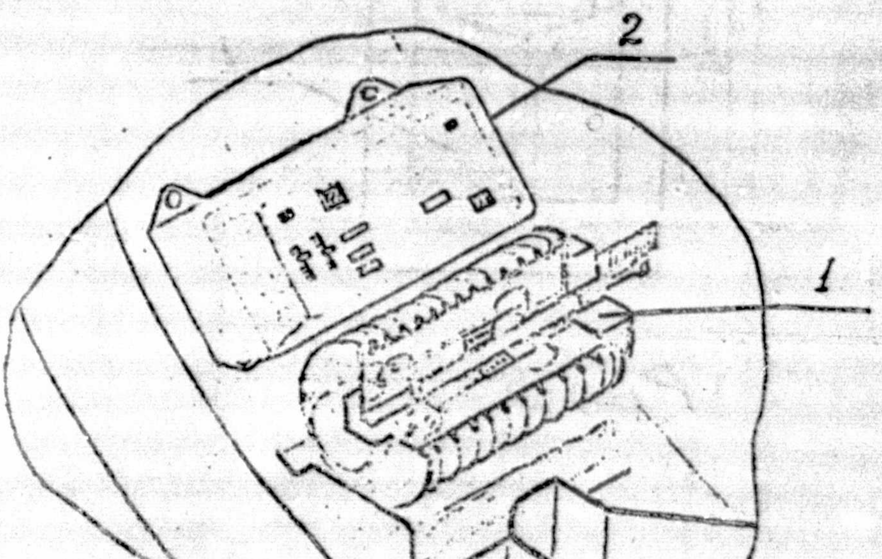

Figure 7. Individual space furnace for obtaining semiconductor materials.

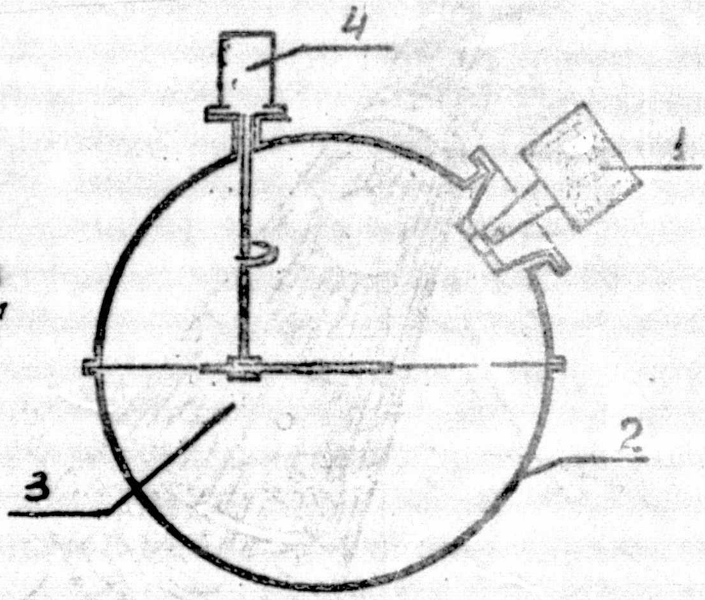

Figure 8. Unit for welding in a state of weightlessness.

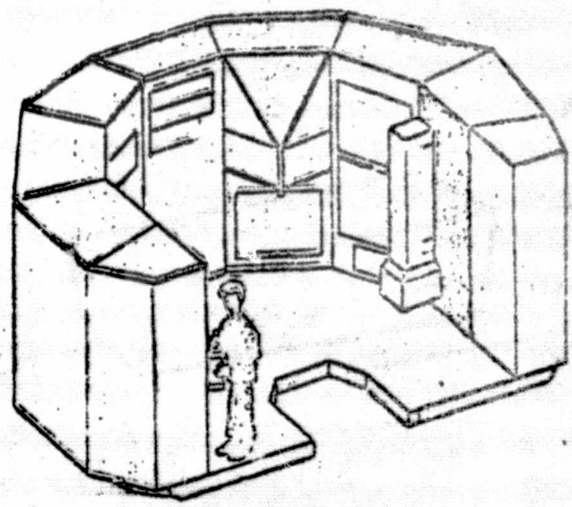

Figure 9. Production space compartment

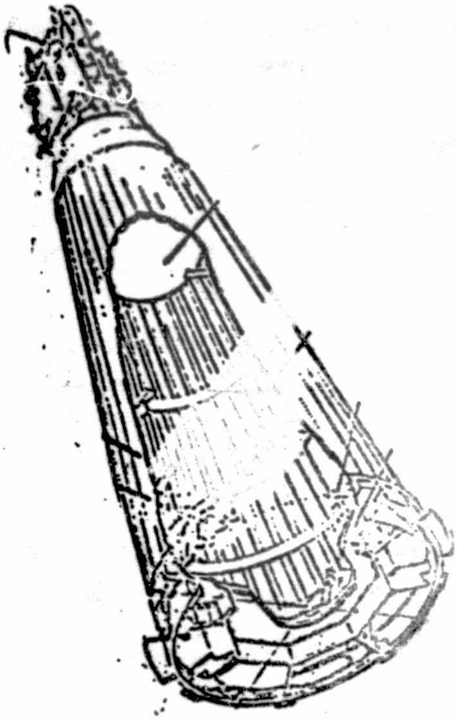

Figure 10. Spacecraft with atomic reactor.

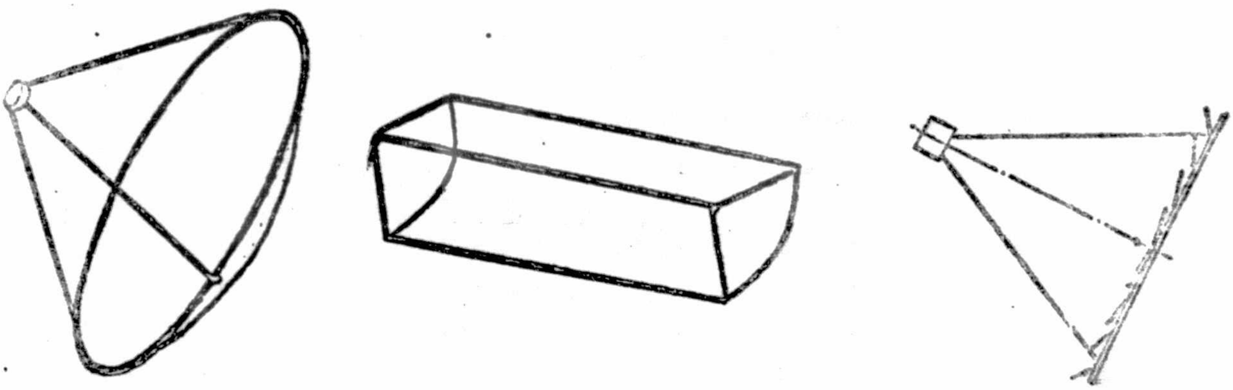

Figure 11. Diagram of solar furnaces.

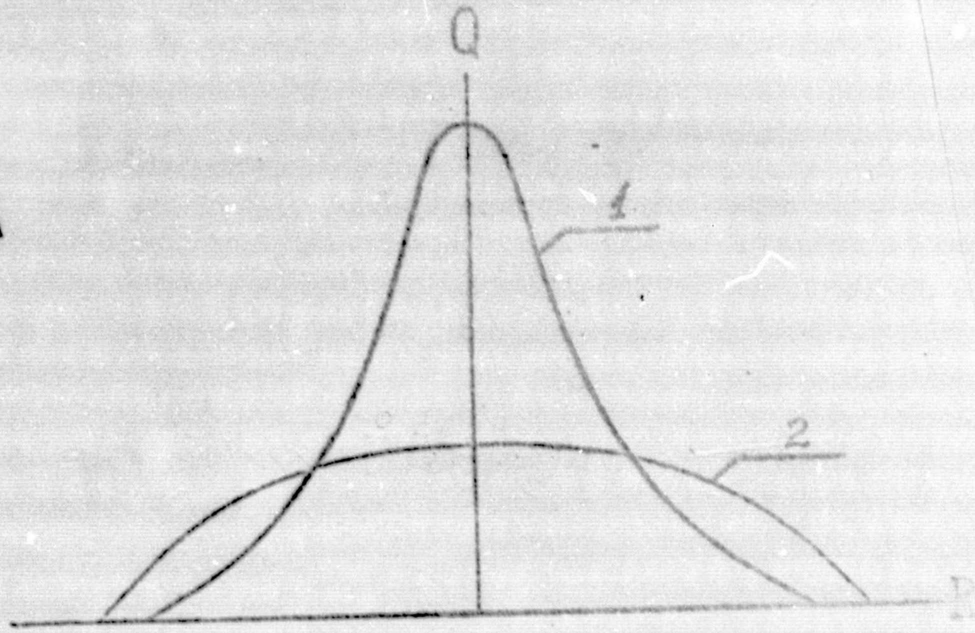

Figure 12. Curves of distribution of energy in focus of solar concentrators.

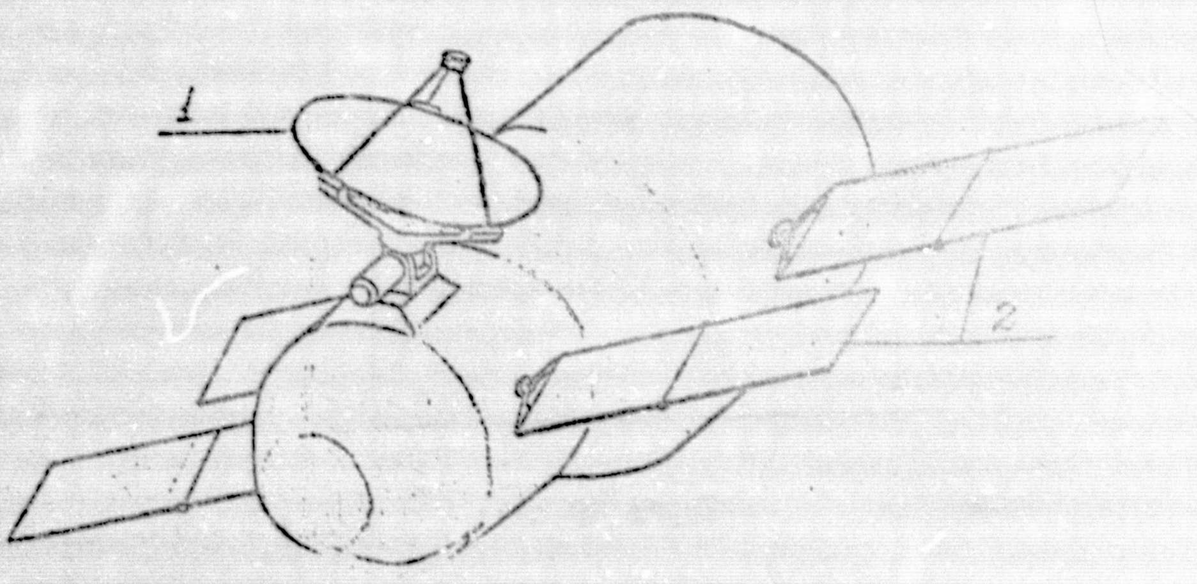

Figure 13. Spacecraft with solar furnace.