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RUSSIAN SPACE PROGRAMME AND ADVANCED MATERIALS DEVELOPMENTS

Dear Reader,

This is number 30 of UNIDO's state-of-the-art series in the field of materials entitled *Advances in Materials Technology: Monitor*. The title of this *Monitor* is **RUSSIAN SPACE PROGRAMME AND ADVANCED MATERIALS DEVELOPMENTS**. This is our second issue covering the space-related material subject: issue number 10 in 1987 was devoted mainly to space-related materials in the United States of America.

The main article for this *Monitor* was written for us by the leading specialist in this field, Mr. Yuri G. Bushuev, Deputy Director General of the Research, Development and Production Corporation "KOMPOZIT" in Moscow.

There has been considerable thinking in recent times on the nature of the scientific and technological experiments to be carried out in space. And many important issues are being debated: Should experiments be technologically oriented? Should appreciable quantities of materials be processed in space? Should these experiments be oriented towards understanding phenomena which will advance the field of materials science? It has been argued for example that experiments on Earth may not be enough to reliably forecast behaviour in a gravity-free or microgravity environment.

Materials processing in space, for example, has several distinct technological advantages such as containerless handling, reduced convection arising from compositionally and thermally induced density gradients, lack of sedimentation and absence of hydrostatic pressure in addition to the availability of high vacuum. All these advantages can be exploited fully in solidification processing.

The growing range of space applications has brought benefits to many countries. While many developing countries use space technology, they have not yet fully exploited its considerable potential. In fact, only the developed countries with advanced technology can fully exploit these benefits. The international community and, in particular, the developed countries with more advanced technology, should intensify their efforts to promote the wider exploitation of space technology by developing countries.

For several years now, the United Nations had a programme for benefiting the developing countries from the spin-offs of technological achievements in space applications. A Committee on the Peaceful Uses of Outer Space has been meeting regularly for several years now to oversee the implementation of the recommendation of an international space conference (UNISPACE '82). For the last few years, the Committee fostered a number of cooperative projects involving other United Nations agencies, particularly in the fields of remote sensing communications, meteorology and hydrology.

Following one of the recommendations of the UN Committee on the Peaceful Uses of Outer Space, adopted during its meeting in June 1991, UNIDO has developed an "Outline of a UNIDO Programme for Realizing the Benefits of New Technology Spin-Offs in Developing Countries" (with particular reference to space technologies). The promotion and implementation of that programme would make space technology spin-offs available to all countries, particularly the developing countries which could not afford to invest heavily in space technologies, and have thus been mainly on the periphery in enjoying such spin-off benefits. This will be a cooperative programme between developed and developing countries for realizing under UNIDO auspices the benefits of spin-offs in developing countries, particularly in satisfying basic human needs. It is planned to be promoted in two phases and the outcome could be a Centre for the Transfer of Space-related Technologies in Developing Countries.

The **INTERNATIONAL SPACE YEAR 1992** was called to coincide with the thirty-fifth anniversary of Sputnik 1, the world's first artificial satellite.

We invite our readers to share with us their experience related to any aspect of production and utilization of materials and especially comments on the subject of this *Monitor*.

Technology Development and Promotion Division

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1. SPACE TECHNOLOGY MATERIALS AND THE CONVERSION

by Yuri G. Bushuev*

The development process of space technology - from the creation of the first spaceships to the execution of the sophisticated Energia-Buran system - has always been accompanied by hard efforts associated with the development and modernization of materials to ensure an optimum balance between the weight and reliability of structures. This necessitated the realization of advanced ideas in the science of metals, metallurgy, welding, polymer chemistry and physics, and the chemistry of complex heterogenic systems.

The development trend in machine-building, especially for the agro-industrial complex and light industries, novel medical equipment and medical tools, shows that the development and organization of machine production that comply with global standards cannot be achieved without the extensive use of new progressive materials. The high material-constructive potential of space technologies can be demonstrated by the fact that in "Energia-Buran", a complex system from the standpoint of technology, about 80 per cent of its dry weight were new materials (dozens of new materials were developed and applied). Over 600 new original design and technological decisions were recommended for use in the national economy of the Russian Federation.

New materials used in the Energia-Buran system operate within the temperature range of -253°C to 2,000°C. It might be worth mentioning some of these materials: high-tensile steels, titanium and aluminium alloys, including cryogenic-resistant, titanium and heat-resistant alloys obtained by granule metallurgy, high-strength glass and carbon containing plastics, carbon-carbon composite materials, heat-protective and heat-resistant materials and coatings, high-modulus beryllium and heat resistant copper alloys, solid greases and sealants.

In figure 1 on page 10, the locations of new materials in the Energia-Buran system are shown.

Of primary importance for the conversion in respect of new materials should be the extensive use of low-alloy, marging high-tensile steels, high-strength aluminium and titanium alloys, non-metallic composite materials, materials obtained by super fast crystallization, and gas-armoured materials, structural and wear-resistant ceramics and new polymer materials for the reduction of material, energy and labour costs, extension of operability and reliability of newly created machines.

An extensive use of the defence industry's experience of the national economy and a reduction of material production will unavoidably cause a sharp increase in the application of new materials. From our standpoint, this increase should be characterized by the figures given in table 1.

The highest growth rates in new materials applications are expected in consumer goods and medical equipment.

Interest in space technology materials has been associated with the fact that their high characteristics permit a drastic reduction of material consumption and improvement in wear resistance and durability of machines and mechanisms.

For example, an extensive use in space technologies is made of low-carbon steels with a strength limit of up to 200 kgf/mm^2, high-tensile casting steels and aluminium alloys with strength limits of 50 and 40 kgf/mm^2 respectively, titanium deformed alloys with strength limits of up to 140 kgf/mm^2 and titanium casting material with strength limits of 90 kgf/mm^2, materials shape memory for the creation of vacuum-tight joints in pipings, glass and organic plastics with strength limits as high as 300 kgf/mm^2 and elasticity modulus of (13-15) 10^3 kgf/mm^2, heat-resistant carbon plastics operating at temperatures as high as 300°C with a strength limit of up to 250 kgf/mm^2, carbon-carbon materials operating at temperatures as high as 3,500°C, progressive manufacturing processes for high-quality semi-finished products, etc.

Some examples of the application of new materials in the national economy of the Russian Federation follow hereunder.

The utilization of small-grain steel 20x3M for the manufacture of press dies to produce granulated combined feed using centrifugal casting technology and subsequent rolling of blanks reduced the cost of dies by 15-20 per cent, about a 30 per cent reduction of metal consumption and a 2.5 to threefold increase in the equipment's service life.

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Table 1. Expected increase in the application of new materials

Field	Growth rate			Purpose and technical and economical parameters
	1989	1991	1995	
Equipment for food industry	1	1.4	3.2	Extension of service time and efficiency. Product loss reduction by 20 per cent.
Medical equipment	1	1.8	3.7	Invalid carriages, prostheses, diaphysical plates, tooling, diagnostic instruments, treatment devices. Two- to fivefold reduction of rehabilitation period.
Household appliances	1	1.5	4.9	Reduction of mass, energy consumption, increase of service life by two to three times.
Chemical industry	1	1.3	2.5	Chemical-resistant reservoirs, piping, tanks for aggressive agents. Substitute materials for stainless steels. Service life as long as 15 years.
Trade and public use	1	1.3	2.4	Dishwashing machines, trading equipment. One point five- to threefold extension of service life.
Light industries	1	1.2	2.3	Thread-driving ceramics components for looms. Increase in efficiency and service life by three to four and improvement of thread quality.
Fuels and energy complex	1	1.2	2.0	Rotary excavators and materials handling equipment. Ensure reliable operation of aggregates in northern regions at temperatures as low as -50°C and weight reduction by 20 per cent.
Machine-building complex	1	1.2	2.0	Structural components for automobile and tractor equipment, filters and valves for automobiles. Heating electric thermal furnaces. Three- to fourfold increase in service life.
Transport	1	1.1	1.8	Better safety of passengers in cases of emergency.
Construction	1	1.3	3.2	Fibreglass structures. Tightening heat-insulating materials based on polyurethane. Reduction of construction terms and costs. Provision of necessary conveniences in buildings.

Note: Scope of application of new materials in 1989 has been taken as equal to one.

This sophisticated technology permits the production of quality blanks, i.e. rolled rings of up to 800 mm in diameter and 80 to 250 mm in height.

Service properties of mass production and newly developed dies for the combined feeding industry are given in table 2.

Dies for the combined feed industry are shown in figure 2 on page 11.

A technology has been developed for the manufacture of knives of special design, cutters of improved wear for meat-processing equipment, i.e. cutters, lard separators, and for wood-working equipment.

Steel 50x15M1Φ, developed for space technologies and resistant while working under corrosive conditions and shock loadings, with a hardness H_{RC}=50-52 after hardening and low tempering, ensures good performance of meat-processing cutters equal to the best world products. Results of comparative tests of cutter knives are given in table 3.

Despite a lower strength limit, the Russian-made low-carbon marging steel has a higher wear resistance. This can be explained by the fact that the low-carbon steel does not form coarse carbide inclusions, which tend to spill out.

Such a steel structure minimizes the removal of metal required to re-grind a cutting tool.

Table 2

Parameter	Value for	
	Ring manufactured in mass production	Ring newly developed out of steel 20x3M
Efficiency, tons per hour	5.5-6.5	6.0-6.7
Work-in time, in hours	16 (average)	5-6
Average service life, to complete material wear in hours	2,650	7,535

Table 3. Results of cutter knife service tests

Steel grade	Strength, kgf/mm^2	Hardness, kgf/mm^2	Quantity of processed meat to complete wear, in tons
40x13	130	45	400-500
Similar to 80x15MBΦ (FRG)	150-160	53-55	2,000
Marging steel	150-160	50-52	3,000

Appearance of the vacuum cutter with a set of blades of marging steels can be seen in figure 3, page 11. Concurrently, work is being carried out to create high-quality cutting tools for the blank-cutting of fabrics in light industries, for fish-processing and forestry needs.

For the take-off structures of the Energia carrier a number of high-tensile steels were developed which do not require heat treatment after welding of structures directly in the field. One of such cold-resistant weldable high-tensile steels, 12xH5[illegible] -III may be used in the manufacture of large-scale structures for hoisting and transport equipment intended for service at temperatures as low as -70°C. This steel (strength not less than 90 kgf/mm^2, yield point not less than 80 kgf/mm^2 and viscosity KCU_{-70} (> 6.0 $kgf.m/cm^2$) can be welded by austenite welding materials without pre-heating and does not necessitate post-welding heat treatment, which is of particular importance for large-scale structures whose assembling and welding are carried out at the service site. Use of this steel permits weight reduction of such machines as rotary excavators by as much as 20-25 per cent.

The application of a number of casting aluminium alloys in the national economy also looks promising.

The chemical composition and properties of these alloys are given in tables 4 and 5.

As can be seen from the table given, the chemical composition of the alloys is complex enough: titanium, zirconium and boron are introduced in the composition as modifiers of the solid solution. Cadmium and indium aid uniform and extensive formation of Guinnier-Preston zones upon ageing of copper-containing alloys. Beryllium protects alloys from oxidation in the liquid state, while bismuth being a modifier of eutectic particles in alloys of the aluminium-silicon system, increases the threshold stress under corrosion of up to 0.9 from $\sigma_{0.2}$.

Versatile properties and a wide range of working temperatures permit the application of these alloys in cryogenic machine-building, instrument components intricate in configuration and computers, in constructions of compensating devices controlling the tension of contact lines on railroads, in prosthesis components and invalid carriages, elevator stair belts used in underground stations, etc. A diagram of a prosthesis component made of aluminium is shown in figure 4, while a thin-walled structure for an instrument is shown in figure 5, page 12.

In developing space technology products, extensive use has been made of processes of powder metallurgy, primarily for the manufacture of tungsten-copper pseudo-alloy parts for units subject to heat attack, and secondarily for the manufacture of critical

Table 4. Chemical composition of casting aluminim alloys

Alloy Grade	Alloying elements, % (w/w)											
	Al	Mg	Si	Cu	Ti	Mn	Bi	Zr	B	Cd	In	Be
A -104	base	0.3-0.5	7.5-9.0	1-2	0.1-0.2	-	0.1-0.3	-	-	-	-	0.03-0.1
A -185	base	0.15-0.35	7.0-8.5	2.3-3.5	0.05-0.2	-	0.15-0.4	-	-	0.15-0.35	-	-
A -246	base	-	-	4.8-5.5	0.12-0.25	0.4-0.6	0.1-0.3	0.05-0.12	-	0.1-0.25	0.05-0.12	-
A -311	base	8.3-9.4	-	-	0.08-0.2	-	-	-	0.01-0.1	-	-	0.05-0.1
A -322	base	6.8-7.2	0.1-0.3	-	0.2-0.4	0.25-0.4	Fe 0.1-0.2	-	-	-	-	0.01-0.03

Table 5. Properties of casting aluminium alloys

Alloy grade	Casting method	Method of heat treatment	Properties			Working temperature range, °C
			σ_B, kgf/mm^2	$\sigma_{0.2}$, kgf/mm^2	δ_5, %	
A -104			30-34	16-19	3-5	-196+200
A -185		T5	36-38	29-33	6-8	-253+200
A -246		T5 T6	43-47 47-51	27-33 40-45	10-15 4-8	-253+200
A -311		T4 T4	33-38 36-40	16-18 17-19	14-18 17-22	-70+100
A -322			25-27	22	6-9	-169+100

parts in hydrogen jets from fast cooled powders (granules). In order to obtain high properties and a theoretical density of materials, the method of hot isostatic pressing was used extensively. The combination of the powder obtaining method and a high cooling rate, as well as the technology and equipment to prepare pseudo-alloys, permitted the fast development of the manufacturing process of parts for valve groups used in automobile engines, in particular the valve seat from high-speed cutting steel of the P6M5 type containing 15-25 per cent copper, which competes with the best foreign analogues. The parts underwent successful testing in the automobile engines of Moskvich cars within the Federation and abroad. It has been estimated that the production areas released as a result of the conversion will be used to set up the manufacture of 4 million valve parts.

The application of technologies for superfast cooling of melts in combination with the method of hot isostatic treatment permitted the development of a new generation of high-energy corrosion-resistant magnets of the neodim-iron-boron system (see figure 6, page 13).

Characteristics of these magnets are given in table 6.

Table 6. Magnet properties

Property	Value
Residual magnetic induction	10-12.8 kgf
Coercive magnetizing force	12-18 kA
Magnetic energy	25-40 MGsA
Kuri temperature	300-400° C
Density	7.3-7.5 g/cm^3
Service temperature	up to 150° C

The application of these magnets as the sources of permanent magnetic fields in generators and electric motors, magnetic collars, suspensions, bearings, tightenings, instruments and medical equipment tools will permit a considerable improvement in technical characteristics or the assignment of new properties.

The technology of hot isostatic treatment has already been successfully applied to improve the strength of drilling equipment and cutting tools used by road-working machines to remove asphalt coatings.

Even beryllium, a specific material used in nuclear energetics and space technology, may also become a subject for conversion. A combination of high elasticity noise spreading moduli with its low density makes this element the best material for electro-dynamic stands. A diagram of the platen of the vibration stand of beryllium 310 mm in diameter is shown in figure 7 page 13. Comparative characteristics of the vibration stand tables of magnesium and beryllium are given in table 7.

From the data given above it can be seen that the beryllium vibration stand tables double resonance frequencies and reduce the acceleration parameter scatter 50-100 times against the tables of magnesium, which makes beryllium the preferable material in testing radio-electronic components and devices.

Of major importance is the use of new progressive metallic materials in the medical field. Thus, high-strength casting aluminium (table 5) and titanium alloys may be successfully used in the manufacture of intricate cast parts for use in medical items (Ilizarov's extension devices, prosthesis components, joint endoprostheses, parts of invalid carriages, etc.). The weight of the parts will thereby be reduced by 20-50 per cent.

Diaphysical plates of cryogenic steel with the strength of not less than 180 kgf/mm^2 and high viscosity are successfully used in curing complex limb fractures. To increase biological inertness of diaphysical plates, a special technique was developed consisting of their coating with titanium nitride, a very biological inert material. Due to the high strength of the plates their width is reduced against that of analogous Russian-made and foreign plates, which permits a two- to three-fold reduction of the rehabilitation period for patients suffering from limb fractures. A diagram of the diaphysical plates made of cryogenically hardened steel is shown in figure 8, page 14.

The development of devices for the osteosynthesis of limb fractures near joints with the form memory effect also shows promise. Specially developed materials have a temperature of the reverse martensite conversion, 32-36°C, while stresses developed in form restoration are within 12-25 kgf/mm^2. A diagram of the device for fixing limb fractures near joints and ensuring their compression is shown in figure 9, page 14.

The material possesses high inertness towards human tissue and permits a halving of the rehabilitation period.

Table 7. Comparative characteristics of vibration stand tables

Table material	Diameter, mm	Resonance frequency, Hz	Acceleration scatter, %
Magnesium	214	4,500	1,000
Beryllium		14,000	10-20
Magnesium	310	3,500	1,000
Beryllium		7,000	10-20
Magnesium	390	2,500	1,000
Beryllium		5,000	10-20

Especially efficient is the application of polymer composite materials in various industries and may be characterized by the following figures:

	Percentage
- Shipbuilding	23
- Construction	21
- Machine and instrument building	21
- Aviation and space technologies	18
- Ground transport	17

The acquired experience for the creation of design and technological solutions and progressive manufacturing processes permits the organization, within the sphere of the conversion, of the production of a wide choice of products. The main items will be:

- Sectional reservoirs with capacities of up to 1,000 m^3 for the storage of liquid and bulky materials;

- Pipes up to 400 mm in diameter for the transportation of foodstuff and dangerous substances;

- Gas and air ducts for the chemical and microbiological industries;

- Heat insulating panels for use in refrigerators and containers;

- Components of invalid carriages and other medical equipment.

A joint Russian-Italian venture, Compital, was founded for the manufacture of containers and pipes.

The manufactured and tested specimens of shell and pump pipes for the oil extraction industry have demonstrated the feasibility of using polymer composite materials in piping for pressures as high as 560 kgf/cm^2. The utilization of such pipes is especially efficient in oil fields high in sulphur, where the service life of low-alloy steel pipes does not exceed two years as a result of their poor chemical resistance.

Plastics may be efficiently used in large-scale thermo-containers and refrigerators, increasing their commercial loading by 20-30 per cent by assigning load-bearing functions to heat-insulating panels and reducing the integral heat transfer coefficient through the reduction of a number of joints as compared to the containers and refrigerators using ordinary metal panels.

Efficient wind power plants of 100-1,000 kW can only be made of high strength and stiff fibreglass plastics. The first environmentally safe plants of 100 kW capacity whose structural components, i.e.fan blades and aggregate body (deflector, spars and support masts) are of fibreglass, are now passing service tests.

The next stage is the use in heavy-duty units of carbon and organic plastics whose unit strength is twice that of the unit strength of fibreglass.

A fibreglass with an alumophosphate binder has been developed for the second stage of the Energia rocket - to protect the units fixing its jets. The development of this plastic laid the basis for a new class of materials intermediate between the polymer composite materials and ceramics. The manufacture of materials of this class is carried out in accordance with the polymer composite material technologies, while the material properties approach those of ceramic materials. It has been confirmed experimentally that glass plastics of this class are incombustible and do not emit any toxic matter up to temperatures as high as 1,200°C. The material has a density of 2 g/cm^3 and a bend strength of about 15 kfg/mm^2.

Modern decorative surface finishes in combination with high flame resistance offer great advantages for the use of this material in finishing interiors and exteriors of different means of transport. The application of this material in place of plastics using organic binders considerably increases the safety of passengers in emergencies. Nowadays, this plastic material is used to cover walls of underground trains. Patterns of this plastic with various finishes are shown in figure 10, page 15.

An efficient sphere of application of polymer composite materials is the friction units operating under heavy-duty conditions at high rates and loads and the effect of low and elevated temperatures in different gaseous and liquid media. However, contrary to the traditional methods of approach towards the development of polymer composite materials in self-lubricating materials for friction units, the polymers should be of high strength, thermal and wear resistant, while their binders should be powder or fibrous materials with low friction coefficients and wear. In order to create non-metallic self-lubricating materials operating at temperatures of up to 400°C and in liquid aggressive media, the binders should be polyimides, polyphenilensuphides, polybenzeimidazols, while the fillers should be molybdenum disulphide, graphite, oxalon and carbon fibres. The main grades of self-lubricating materials and their properties are given in table 8, and a diagram of parts made of self-lubricating composite materials is shown in figure 11, page 15.

As can be seen from the table, self-lubricating materials ensure operability of units within a wide range of temperatures and loads. The composition of Syntec uses a fabric of heterocyclic polymer-polyoxadiazol Oxsalon and carbon fabric Ural, and formaldehyde resin SF-29, which gave thermally resistant sewn structure approaching the carbonated structure and ensuring stable anti-friction properties upon transition between the plus and minus temperatures and durable (1,000 hours) operability at loads of up to 80 MPa. The material Aftal is successfully utilized in the construction of excavators, including those operating at temperatures as low as -50°C.

Improvement of technical parameters of space technologies necessitated the creation of erosion-resistant materials that possess high thermal stability and strength to temperatures as high as 3,000°C. A wide selection of such materials has been developed on the basis of carbon-carbon, ceramic and carbon-ceramic compositions. Research has been carried out covering optimization of the body structure, deliberate change of deformation properties of the die and adhesion control on the die-fibre boundary; research has shown the feasibility of developing carbon-carbon materials with a strength of no less than 40 kgf/mm^2 and ceramic materials with the strength of no less than 100 kgf/mm^2. Main efforts in the development and improvement of carbon-carbon materials is to improve their strength and oxidation resistance while for the ceramic materials based on oxides, nitrides and carbides the main purpose is to increase destructive viscosity.

These materials, that were developed specifically for space technologies, have also found their use in various industries such as materials for heat insulators and melting crucibles for metals. Carbon-carbon materials are used to manufacture heating elements for high-temperature furnaces, braking devices and hot-pressing moulds, bearings and pipings for chemical machine-building aggregates, and recently for endoprostheses for the coxofemoral joint (figure 12, page 16).

Several successful operations have been performed on patients with thigh cervex fracture. The material is outstanding for its high compatibility with human tissue, while the manufacturing process for the endoprosthesis permits complete reproduction of the bone tissue.

Extensive use of structural ceramics obtained on the basis of aluminium oxide with a microhardness of 1,600-2,000 kgf/mm^2 permits the modernization of light industries and the manufacture of chemical fibres. Threads may pass through looms five to seven times faster if contact parts made of such ceramics are used. The strength and quality of threads also increase by approximately 15-20 per cent. Wear resistance of the thread driving parts made of aluminium oxide is three to five times higher than that of the traditional metal materials and porcelain.

New perspectives in developing and modernizing materials may be opened upon introduction of cosmic technologies, i.e. the production of materials under zero gravity conditions. Zero gravity causes considerable effect on heat and mass transfer processes, hydrodynamics, phase passages and superficial phenomena.

About 500 experiments carried out during rocket launches and on the automatic orbital complexes of Foton and the space stations Salyut and Mir permitted the determination of the most promising materials and the scope of their possible utilization (figure 13, page 17), viz.:

- Thallium arsenide for the production of integrated circuits;

- Germanium, mercury diiodide and cadmium telluride for infra-red and gamma-ray sending units;

- Cadmium sulphide and zinc oxide for perspective ultraviolet and blue-green lasers;

- Protein crystals (neurominidase, reverse transcriptase, etc.), for the creation of qualitatively new treatments for influenza, AIDS and other illnesses;

- Protein preparations for medical purposes of high purity (insulin, tumour necrosis factor, hepatitis B vaccine, etc.);

- Highly productive cells - producers of feed vitamins and antibiotics (riboflavin, flavomicine, tylozine, etc.);

- Gradans (glasses with variable refraction index) for perspective optical systems;

- Monodisperse filled or unfilled latexes for the preparation of diagnostics and transport of medicines to affected areas.

The technical requirements for the manufacture of complex semiconductors and biological preparations in space are given in table 9, while the conditions available on spaceships are drawn in table 10.

The given data demonstrate that space vehicles Nika-T and TMII fully satisfy the requirements for the material production in space.

It should be concluded that new materials may determine the development of civilization and permit the realization of new engineering designs, as well as help in the solution of our planet's nutrition problem and health protection.

Table 8. Properties of self-lubricating materials

Property	Material grade				
	Syntec	AFTAL	EONIT-3	FENAN	Polyar
Density, g/cm^3	1.1-1.2	2.0-2.5	-	2.1-2.2	1.3
Friction coefficient	0.1-0.15	0.1-0.2	0.1	0.08 at 200°C	0.1-0.2
Wear Intensity, mm	1 10^{-9}	1 10^{-9}	0.5 10^{-9}	1 10^{-9}	0.5 10^{-10}
Unit load, MPa	80	250	-	150	-
Service temperature, °C	-150-350	-253- -+250	-250- -+250 shortly: up to 400	-150- -+600	-190-+200

Table 9. Technical requirements for the manufacture of material in space

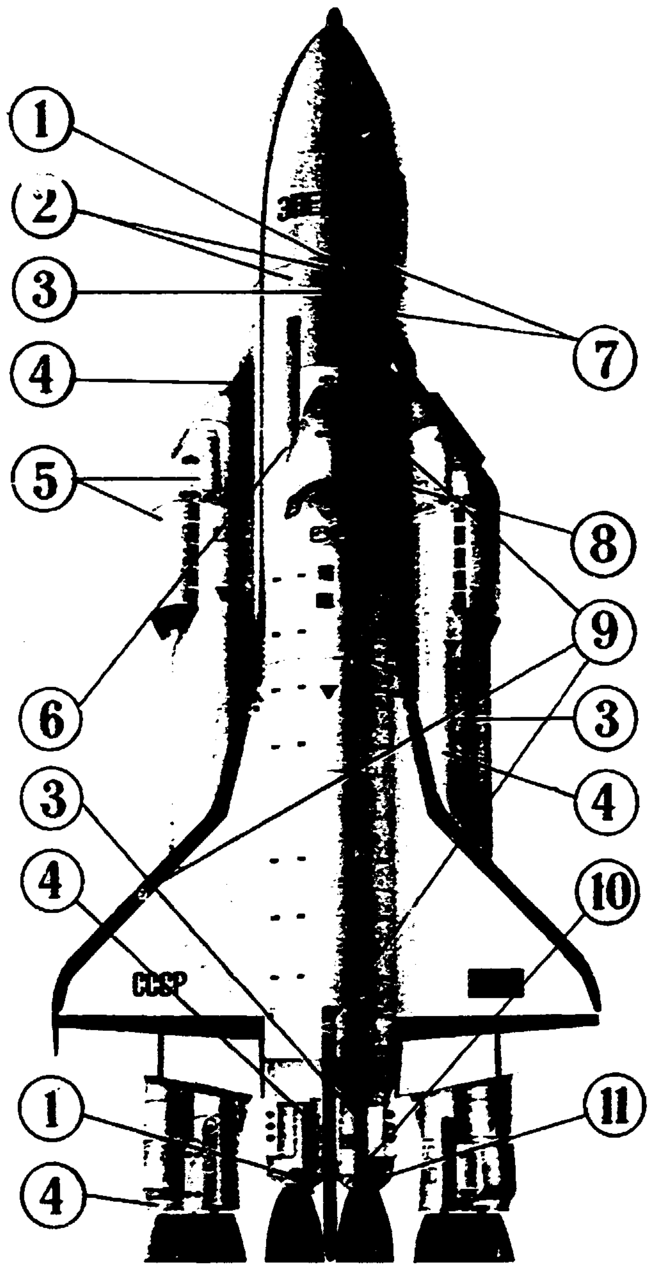
Material	Power, kW	Acceleration	Duration of process, hours	Returnable mass, tons per year	
				Net	Gross
Complex semiconductors	5-30	10^{-4}-10^{-5}	up to 250	1.0	2.0
Biological preparations	0.5-5.0	10^{-3}-10^{-6}	up to 400	up to 0.01	0.5
Fundamental research	0.5-2.0	up to 10^{-9}	up to 400	0.05	0.1

Table 10. Spacecraft conditions

Spacecraft	Power, kW	Acceleration	Life, years	Returnable mass, tons per year	
				Net	Gross
Foton	0.4	10^{-4}	0.04	0.03	0.05
Mir	2	10^{-2}-10^{-3}	2-3	0.02	0.03*
Nika-T**	4-6	10^{-4}	0.4	0.05	0.1
Buran	to 25	10^{-5}	0.1	0.3	0.5
Technological module TMII**	25-40	10^{-9}	5	1.0	2.0

* For one flight of landing module "Soyuz".
** Now only designed.

Figure 1. Space rocket system "Energia-Buran" - general view.



1. High-strength marging steel.
2. High-tensile titanium alloy.
3. High-tensile aluminium alloys.
4. Heat protection.
5. Carbon based plastic.
6. Cryogenic thermoinsulation.
7. Cryogen-resistant aluminium alloy.
8. Beryllium casting alloy.
9. Carbon-carbon composite materials.
10. Cryogen-resistant steels.
11. Heat-resistant nickel alloys.

Figure 2. Matrices made from steel of 20x3M type for animal formula feed manufacture.

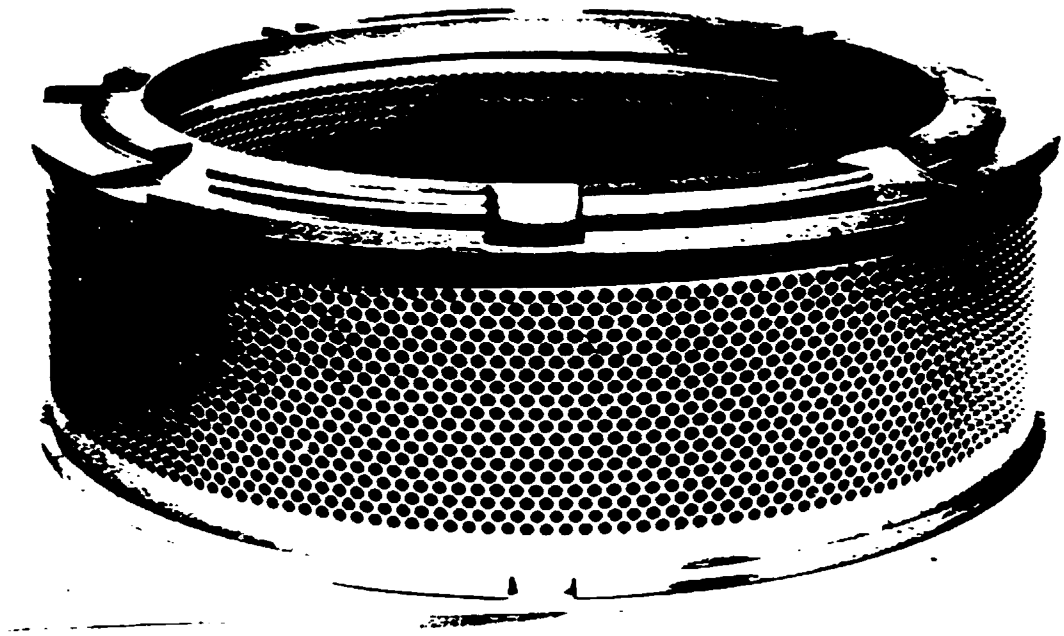


Figure 3. Vacuum cutter with knives made from marging steel.

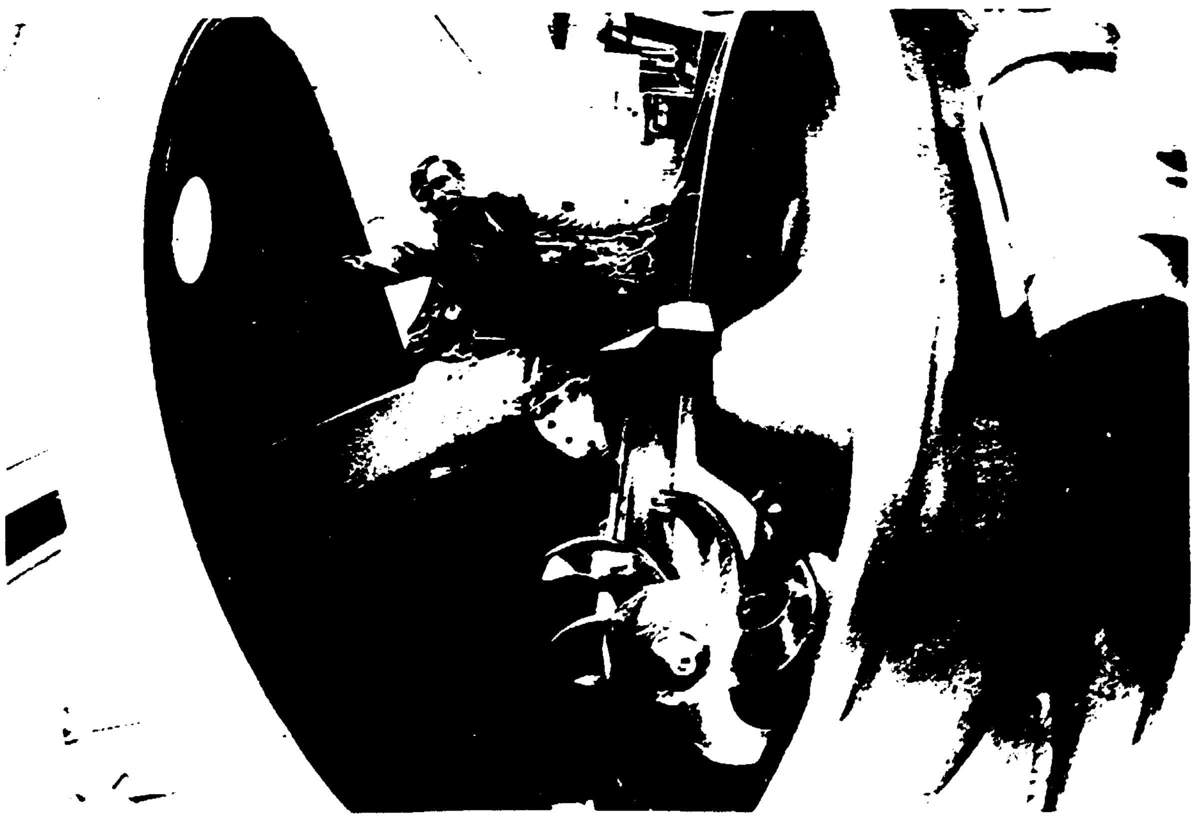


Figure 4. A knee joint part made from Al-based alloy.

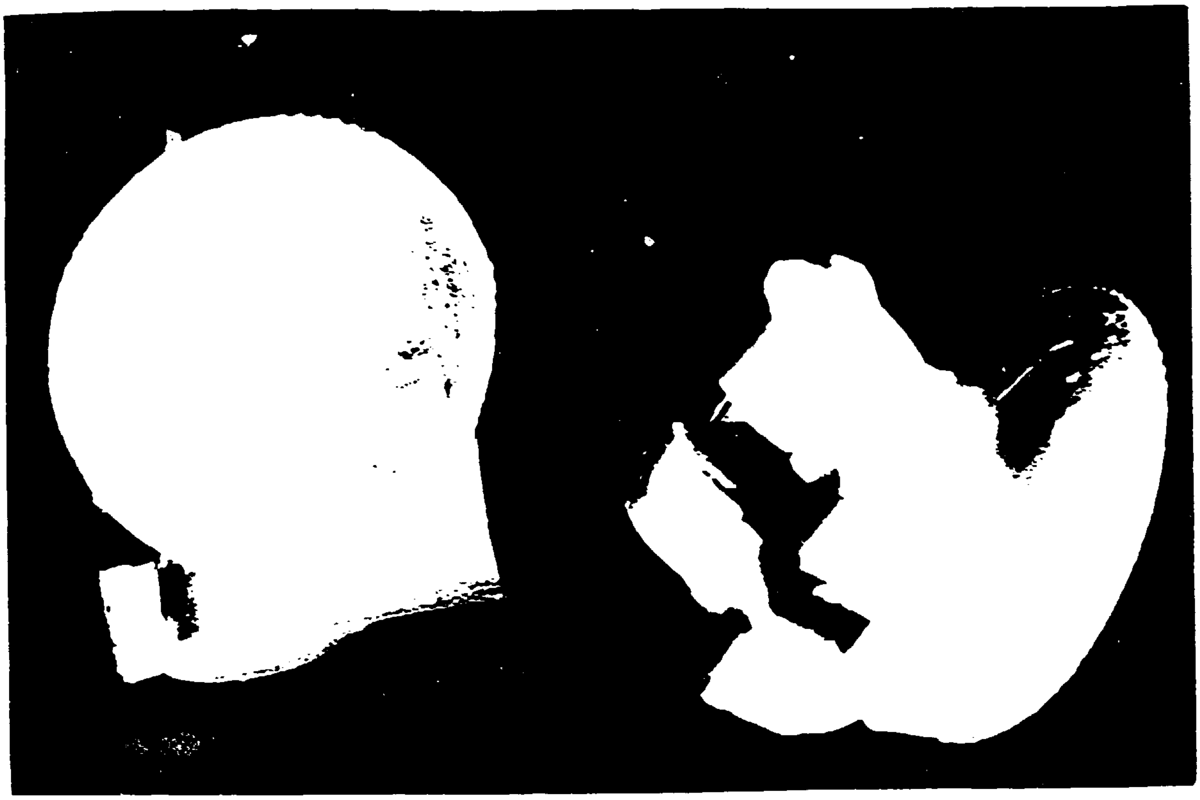


Figure 5. Thin-walled Al casting for devices.

Figure 6. High-energy corrosive resistant Nd-Fe-Br magnets.

Figure 7. Vibratable stand made from beryllium.

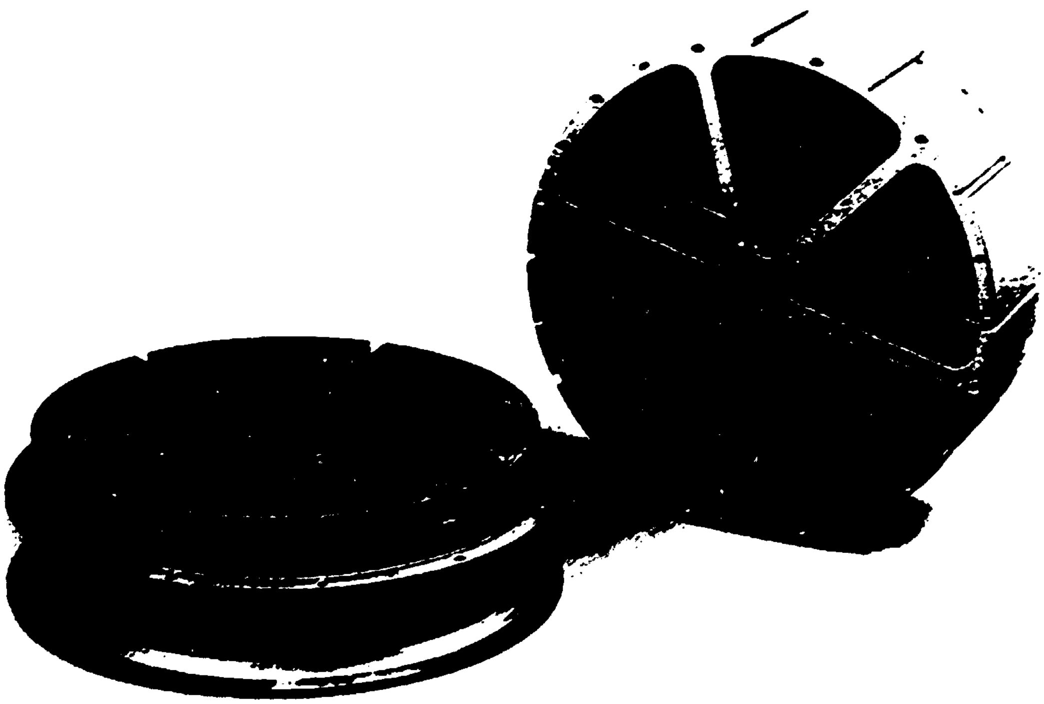


Figure 8. Diaphysical plates made from cryogenic reinforced steel.

Figure 9. Bone breakage fixature made from shape memory material.

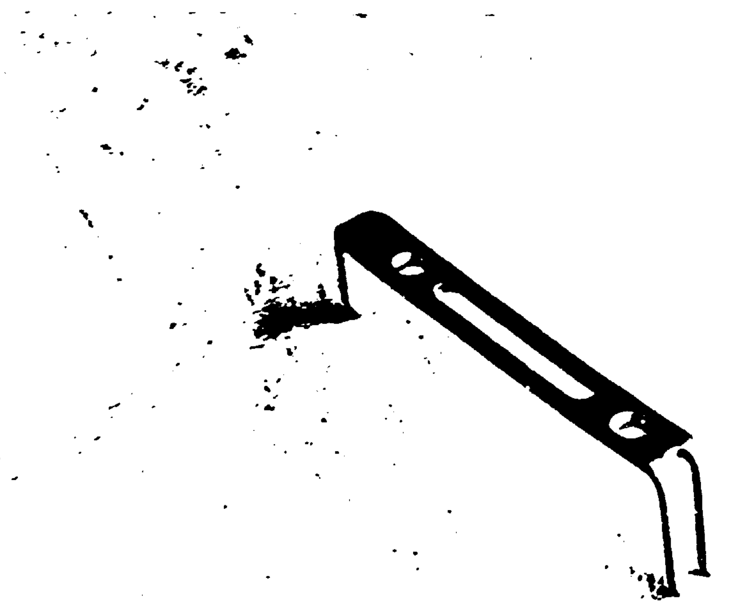


Figure 10. Fire-proof plastic.

Figure 11. Parts from self-lubricating composite materials.

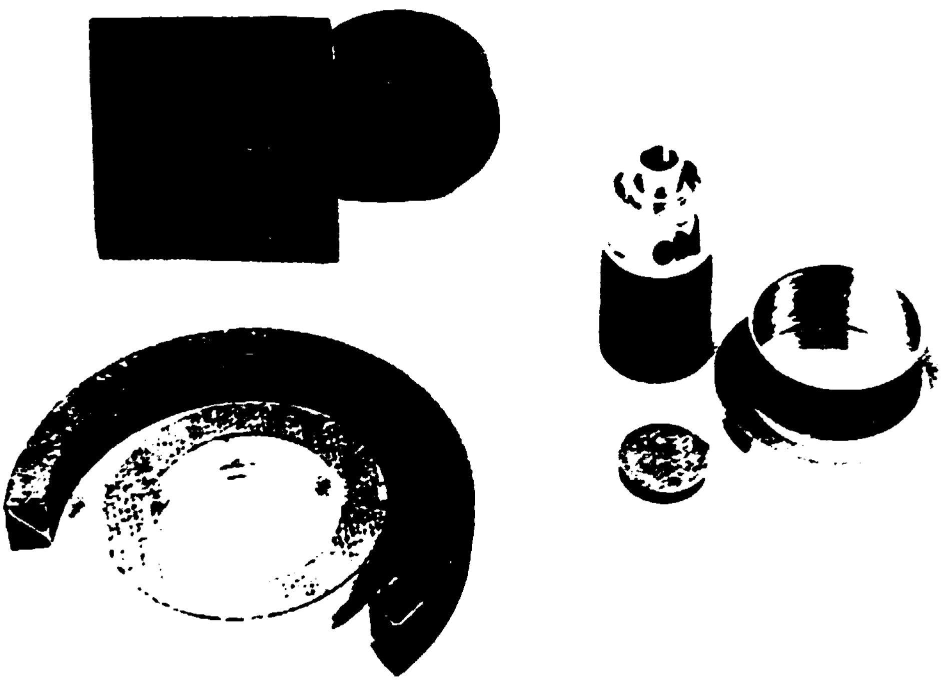


Figure 12. Hip joint endoprostheses.

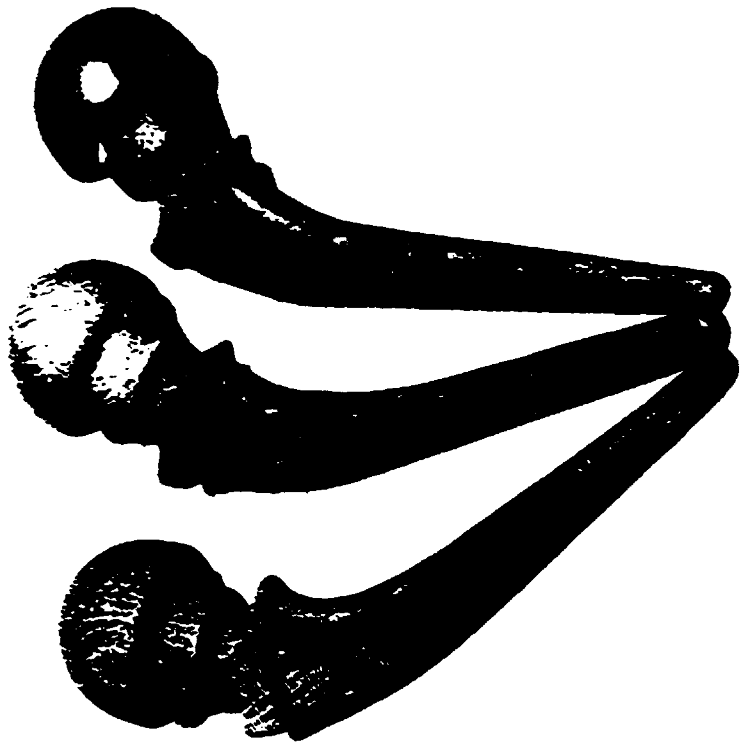
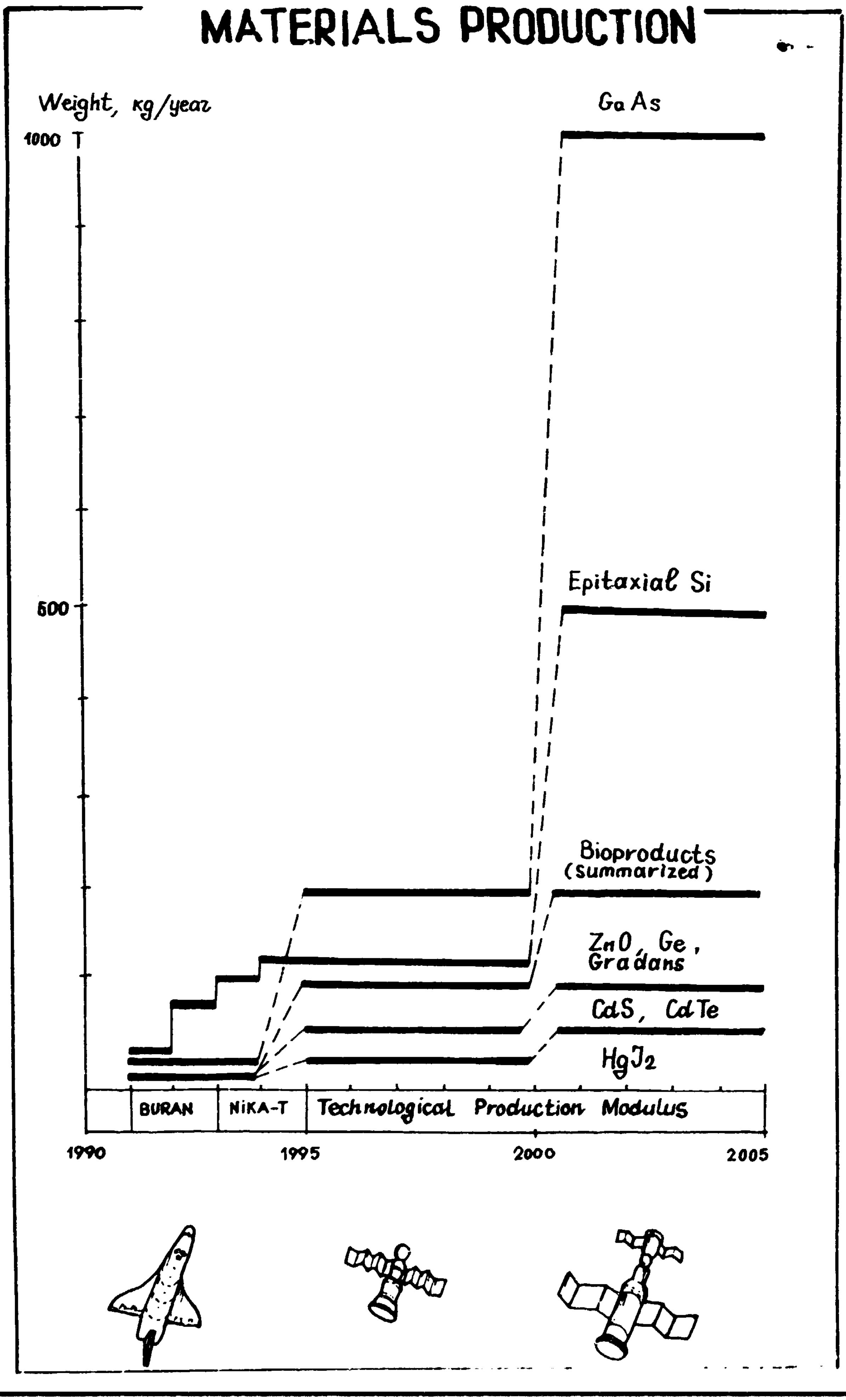


Figure 13. Range of products manufacturing in space.



2. TECHNOLOGY IN SPACE, ACHIEVEMENTS, PROBLEMS AND PROSPECTS

by Yuri G. Bushuev*

The last decades have seen a new direction in the progress of astronautics, namely the industrialization of space.

Work on mastering a new production medium - space - is carried out over a wide range and incorporates, for instance, the science and technology of space materials.

The science of space materials involves a number of interrelated problems:

- Study of the processes of heat-mass transfer, phase transitions and surface phenomena under conditions of weightlessness with the aim of developing corresponding fundamental scientific disciplines;
- Improvement of present production processes on this basis;
- Creation of a complex of on-board production installations and testing the production processes.

A new scientific discipline - the physics of weightlessness - originated and is fast developing at a junction of the theory of heat-mass transfer, hydromechanics, theory of phase transitions and surface phenomena. It studies the physical conditions that occur on board spacecraft. Weightlessness physics represents a scientific basis for materials science and technology in space.

At present, studies on space technology problems are mainly carried out in the Russian Federation, the USA and Europe.

The first experiments in space technology were performed in 1969 by the Soviet cosmonauts G. S. Shonin and V. N. Kubasov on board the spaceship Sojuz-6. With the help of a "Vulcan" installation, experiments were carried out on welding, as well as studies on the processes of melting and solidification under conditions of an orbital flight.

Studies in the field of space technology began in the USA at the end of the 1960s by a series of experiments conducted on releasing towers and then in aircraft laboratories. During the flights of the US spaceships Apollo-14, -16 and -17 in 1971-1972, a number of demonstration experiments were carried out, including the first experiments on electrophoresis separation. A considerable step forward in the development work in space technology were the studies, carried out in 1973-1974 on the Skylab orbital station followed by experiments within the framework of the Soviet-USA project Sojuz-Apollo in 1975.

Regular research into space technology began in the USSR on piloted spacecraft in 1976 with experiments on the long-lived orbital station Salute-6. A number of experiments were carried out on the peculiarities of crystallization in weightlessness, the behaviour of liquids and occluded gas in the liquids with the help of crystal and diffusion instruments, etc. A technology for soldering the permanent joints in space was tested in the Reaction installation. An extensive work programme in space technology carried out on high-temperature electric heating furnaces Alloy 01, Crystal and others on growing monocrystals from a melt of directed crystallization methods, steam and chemical transfer, epitaxy, etc., was carried out on the Salute-6 station.

Already these first research experiments have revealed a number of technological process peculiarities when obtaining materials under orbital flight conditions of a spacecraft. The experiments on growing crystals from melts revealed phenomena of melt separation from non-wettable walls of the ampoule and heavy action of the Marangoni convection on a mass transfer in the melt as a priority role of diffusion. In this case, the obtained crystals themselves turned out to have a lower density of dislocation by 1-2 orders and increased macro- and micro-uniformity of distribution of the alloying impurities.

Technological process peculiarities that were revealed in order to obtain materials on board a piloted orbital station stimulated the carrying out of studies on the technology in space in automatic spacecraft as well. During the period from 1976 to 1982 a programme of investigations was carried out with the help of vertically launched rockets with a weightless time of about ten minutes. The materials science experiments were carried out with the use of chemical exothermal heaters (referred to as BKT). More than 140 experiments were performed with the use of semiconductors, glass and composite materials. The peculiarities of alloy structures formation were studied from non-mixing components under Earth conditions (Pb-Zn, Bi-Zn, Cu-Cr, etc.), eutectics (Al-Cu, Mn-Bi, etc.), multi-component glasses (phosphate, borate, etc.). The strictly regular structures of eutectics and improved optical characteristics of laser glasses were obtained, as well as confirmation of the behaviour peculiarities of melts, depending on the

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moistenability of ampoule walls. Semiconductor monocrystal specimens (Ge, etc.) were obtained, while providing the replacement speed of a crystallization front higher than the slip speed of dislocations.

The launching of the Soviet satellites Cosmos-1645 in 1985 and Cosmos-1744 in 1986 started a period of using special automatic spacecraft (Photon) for space technology experiments.

So far, about 150 experiments have been carried out with various classes of materials on installations-furnaces with gradient and isothermal zones of heating (Zone 01, Zone 04, Alloy 02) by using directional and volumetric crystallization methods, steam and chemical transfer and crucibleness zone melting. These experiments once again confirmed the reduction of dislocations density (approximately by an order) and an increase in the uniform distribution of monocrystal impurities, obtained in space (Ge, alloyed Ga, Te, Sb; InSb, alloyed Te, etc.) at the expense of suppressing thermo-gravitational convection and withdrawal of melt from the ampoule walls. Experimentally confirmed was the efficient suppression of convection or convective mixing of the semiconductors melt with the help of magnetic fields in case of a zone melting. An increase of the coercive force two to three times of the magnetic alloys $(TbGd)_3$ Co) and others was revealed, as well as peculiarities on the formation of antifrictional alloys (Pb-Zn, Pb-Al, etc.) structures and superconducting ones (NbSnTe etc.) in weightless conditions. A more uniform distribution of magnetic inclusions was achieved in magnetic-and-optical glasses, in this case the inclusions themselves had larger sizes.

Gradans - glasses with a variable index of refraction in diameter, which are practically of a parabolic profile - were obtained. The peculiarities of polystyrene and polyacrolein latex polymerization in weightlessness (Biser (beads) equipment) were studied and larger latexes with magnetic nuclei were obtained. When crystallizing zoolites, optimal conditions were found for the formation of a highly improved gel. Ten experiments were carried out on the separation of albuminous preparations by using the methods of flow electrophoresis on the NAF equipment "Biophispribor" and of column electrophoresis on the Kashtan equipment. A relative improvement in dividing the biopreparations into fractions (α_1-thymosin, $\alpha 2$ - genetically engineered interferon) was demonstrated. Several biocrystals suitable for X-ray structural analysis were grown in spacecraft conditions. Micro-organisms for the producers of vitamins and antibiotics were exposed in the Biom cassette of the Kompozit Scientific and Production Association.

In individual cases, the micro-organism strains have increased their activity by approximately 50 per cent, compared to reference specimens. The experiments on the crystallization of proteins (influenza virus) were also carried out on the Biocryst installation (the Rotor Scientific and Production Association) on the automatic spacecraft Bion.

Especially wide investigations on space technology were realized in the Soviet national programme and the Intercosmos programme from 1977 to 1985, when an orbital complex Salute-6 - Progress and then Salute-7 - Sojuz - Progress and finally Mir began to function in space.

About 400 experiments on the physics of weightlessness have been carried out on piloted orbital stations. The basic directions of experiments were fundamental studies on hydromechanics, heat-transfer, surface phenomena, phase transformations, structure-formation, electromigration processes in biocontaining media. By using the instruments for measuring micro-accelerations on Pion, Vibration and other equipment of the Kompozit Scientific and Production Association, as well as on the Biryuza, Isparitel (Evaporator) of the Ukrainian Academy of Sciences and others, it was possible to obtain data on the mechanism of the birth and development of the Marangoni convection, the drift of solid and gaseous inclusions in model media at various configurations of temperature fields while on board. The structure-formation dynamics in disperse media (aero- and hydro-soles) were studied. The investigations of peculiarities of the heat-mass transfer in solutions and melts, when crystallizing the pure metals and alloys at solidification of glasses were continued on the Crystal equipment, mirror-radiation furnace, Alloy 01, Crystallizer and others. Conditions for predominance of diffusion transfer to the front of crystallization, nature of the streakiness origination in the specimens of additive semiconductors, etc. were established. A strong action by the capillary convection on mass transfer in the melts was shown again and new phases in composite alloys were found.

On the Pion-M equipment, realization was made of an experiment to obtain monocrystals by using Stepanov's method under conditions close to weightlessness. The experiment demonstrated the possibility of growing the profiled monocrystals with higher growth rates than underground conditions by expanding the regions of the liquid zone stability.

A study cycle was carried out on the Tavria, Robot, Svetlana and Ruchei (stream) equipment of the Rotor Scientific and Production Association on dividing albuminous preparations (interferon, interleukin, etc.), cells - the producers of interferon, insulin, flavomycin, etc. - by using isoelectrofocusing and zonal electrophoresis methods. Use was made of column stationary and flow type equipment. The studies established an improvement of the resolving power of separation processes and an increase of the productivity of processes by approximately two orders. The Biocryst equipment of the Rotor Scientific and Production Association and Ainur (the Biotech Scientific and Production Association) of the Azerbaijan Academy of

Scieeces were used to perform the crystallization processes of model proteins, the protein of influenza virus - neuraminidase. The individual crystals turned out to be slightly larger than the Earth analogues.

A considerable part of the experiments on piloted spacecraft was of an application character, being carried out with industrially important materials, especially with semiconductors. The CDTe, GaAs and other crystals were obtained, with a lower density of dislocations by 1-2 orders, increased macro- and micro-uniformity of the alloying impurity distribution in monocrystals compared to the Earth analogues. In a number of cases, the structural and electrophysical parameters of semiconductor specimens obtained in space did not improve.

In order to test the technology for gaining promising semiconductor materials of high quality, special installations were developed, among them Corundum, Gallar and Optizon; for the production of the pilot industrial batches - Crater B (the Scientific Centre of the Scientific and Production Association). Based on the results of the investigations, a range of semiconductors for the space production was determined: epitaxial silicon, gallium arsenide, cadmium telluride, cadmium sulphide, zinc oxide, mercury diiodide and some others. These materials are used in the most important fields of electronic engineering. It is anticipated that in the near future, as special spacecraft constructed for the production of materials (see figure 1, page 23) and a long-life orbital station complex are launched into orbit, we may solve the problem on their profitable production in space and satisfy the demands of the electronics industry for these high-quality products. The first space specimens have shown, for instance, that the silicon epitaxial structures feature a unique uniformity of electrophysical parameters and allow materials to be created that have an increased integration extent and fast response; gallium arsenide monocrystals have an extremely low density of dislocations and high electrophysical parameters for the production of various electronic instruments, while the zinc oxide monocrystals are suitable in their ideal structure and uniformity for the manufacturing of the UV-lasers.

At present, already used or ready for use in the current year on piloted spacecraft are the Zone 02 installation for the fabrication of ultra-pure and alloyed germanium for sensors, and Gradient, whose basic purpose is to obtain gradans, and the Alloy 03 installation.

Thus, it may soon be possible to start a pilot production of a number of semiconductors and gradans, as well as obtain batches of individual bio-preparations and albuminous crystals in the interests of ground technologies.

It should also be noted that along with the testing of the technology for the production of concrete materials in space, fundamental studies are continuing, which in combination with a mathematical modelling of the studied phenomena, assist in understanding the role of weightlessness as a technological factor in the quality improvement of manufactured products and help to improve the technological processes and equipment for the production of materials both in space and ground conditions.

Parallel to the investigations on piloted spacecraft, experiments were carried out in the USA, Western Europe and Japan, as well as in the Soviet Union, on materials science by using high altitude rockets, directed mainly at obtaining metal alloys and semiconductors.

Especially intensive studies in the field of space technology were carried out in the scientific programmes of the USA and the European Space Agency after putting into service the multi-time transport space complex Space Shuttle and Spacelab orbital units. During the flights of these spacecraft, a number of important technological experiments were realized and many of them were directed at solving the commercialization problems of space production. In this case, the foreign specialists paid greater attention than we Russians to experiments on producing biological preparations in space, which will obviously have a considerable economic impact in future. The situation is now being corrected and Russia is planning to perform a number of biological experiments on the newly developed equipment (ultra-pure vaccine against hepatitis B on the Ruchei-2 equipment, cell producers of vitamins on the Shtamm (Strain) equipment, etc.).

At present, an analysis has been made of the situation with respect to the level of micro-accelerations on board existing and some of the future spacecraft specially constructed for space production (see figure 2, page 24). It is obvious that there is no absolute weightlessness on board spacecraft.

To provide the preparation to proceed from experimental studies to pilot-industrial production in the Earth orbit, requirements are formulated for spacecraft conditions which are required in order to obtain high-quality products. Work has been started to set up specialized space objects (see figure 3, page 24). Based on the requirements for the level of micro-accelerations on board (not more than 10^{-10} G), it is desirable to locate the materials production equipment near the spacecraft's mass centre; in this case the preference for its arrangement is given to independent pilotless space objects, since no dynamic disturbances can take place as a result of the presence of personnel and, in addition, no expenses are required to set up and install a life-support system.

Since the dynamic situation in the production equipment zone is one of the most substantial factors when determining the final product quality, it is necessary to use the production equipment vibration elimination structures, especially when using a piloted spacecraft.

The Kompozit Scientific and Production Association has created and uses an experimental module (Vibration) on board the orbital station Mir to study the influence of vibrating micro-accelerations on the run of production processes when manufacturing materials, and especially on the heat-mass transfer in liquid phase. The suspension to protect against vibration is also developed, which enables the vibro-isolation of an object with a mass of 5 kg and possesses a good carrying capacity under orbital station conditions.

There is no doubt that, after accumulating true data on the positive influence of space conditions on the production processes of high-quality materials and taking into account or eliminating negative factors, industrial manufacture of products will be organized in independent orbital stations.

The organization of large-scale production in space will require high power capacity, high-temperature production equipment and correspondingly the powerful systems of energy supply (30 kW and more). So far, the basic type of equipment for the high-temperature production processes is represented by electrothermal installations and the power systems are based on solar batteries. It is considered irrational to use electric power obtained by photoelectrical conversion of solar radiation to perform heat production operations. The heat processes can be carried out directly by solar radiation heat by using the concentration systems, by increasing the density of solar radiation flux to a level necessary for its efficient use. The high-intensive radiant fluxes, obtained with the help of solar radiation concentrators, may be used to perform production processes with sufficiently large objects.

In preparation for the use of solar radiation directly for heat processes, the optical furnaces (Optizon-1, etc.) were produced, based on artificial sources of light. Such furnaces allow comparatively small reflectors to obtain the luminous fluxes capable of irradiating small objects with a high intensity. They are successfully used both in ground conditions and in spacecraft conditions to provide radiant heating while performing a number of experimental and manufacturing processes based on radiation-and-heat-treatment technology. In many cases they are more efficient compared to electric heat-treating furnaces on the basis of an ohmic heating. The optical furnaces are of special importance for providing high-temperature production processes. By a relatively simple method, they permit the melting of refractory joints at temperatures of up to 3000K and grow mono-crystals from melts in a wide range of temperatures and pressures. The features of radiant heating in the optical furnaces successfully combine with the conditions of weightlessness and vacuum. Under weightless conditions, the optical furnaces enable containerless heating. As a result, conditions are created to obtain pure materials; that is, the appearance of impurities in materials caused by contact with a contaminated atmosphere, crucibles or the heater, is practically impossible.

The space vacuum is supposed to be used to obtain ultra-pure materials for fundamental studies on thin films, as well as for studying surface phenomena, applying the reflecting coatings on mirrors and developing materials with synthesized micro-structures, such as superlattices in electronic and photoelectronic devices. For such applications, it is proposed to set up a space supervacuum research module (SURF) in the USA.

The Kompozit Scientific and Production Association has started work on developing a solar furnace. During the development and testing of this furnace (based on the concentrator of solar energy), use shall be made of the experience in technological processes on rocket probes through the use of solar concentrators and the known results of realizing the production processes with the help of optical mirror-radiant furnaces (based on artificial sources of radiation) on the Soviet orbital station Mir and piloted USA Spacelab orbital units. In Russia, it is planned to create an experimental base for the ground testing of space helium installations by the production processes used to obtain materials. The realization of this work is associated with a number of difficulties. First of all, it is very difficult to create an accurate concentrator with a high reflecting power which is stable to exposure to electron and proton fluxes of a high power under space conditions. However, despite the various difficulties, the application of solar energy concentration systems represents one of the promising ways of improving the energy-mass-dimension and economic indices of spacecraft with an increased on-board power engineering for the power-intensive processes of industrial production of materials in orbit. In addition, the concentrator should be stable to the effects of meteor particles and ultraviolet radiation. For such a spacecraft, the power plant supplying electrical energy is also an important component and to a considerable extent determines its mass, efficiency and cost. Despite the fact that solar batteries have proved themselves to work well in space, they may be out-competed by power systems with turbogenerators.

Therefore, a hybrid power plant is under consideration to supply the orbital space station complex with electric energy, containing photoelectric converters and turbogenerators. Power systems with turbogenerators have a parabolic mirror that focuses the solar rays, and a power receiver. The power receiver contains a melting material (salt), accumulates the concentrated heat energy and a working substance (gas) activates the turbine, which rotates the electric generator. Under the action of solar radiation heat, the salt melts and when the station is in shade solidifies by giving the heat to a working substance.

The efficiency of the turbogenerator system is determined first of all by the efficiency of the heat engine, which comes to about 30 per cent and the efficiency of the heat energy accumulation (over 90 per cent). As a result, the efficiency of the turbogenerator system may be considerably higher than that of a silicon solar battery (14 per cent).

The turbogenerator power systems have so far not been used in space, but there is a reliable technological base for their production for ground purposes and aviation. It is assumed that the most suitable heat engines are turbines, operating on the Renkin or Braiton cycle; the preference to one of these cycles will be given after performance of comparative tests.

It is hoped that the hybrid power system will combine the best qualities of photoelectrical systems (high reliability, low expected risk, low sensitivity to guidance errors) and systems with turbogenerators (low cost of the basic assemblies and area of the mirror), especially important if the power systems are designed for long-term use.

When assembling large-scale constructions in space, use may also be made in the processes of welding and soldering of direct heating by concentrated solar radiation.

Likewise, the use of a self-propagating high-temperature synthesis process (SHS) is rather promising. Welding by the SHS method is useful in the absence of power sources for the traditional methods of welding and soldering or in the event of their low efficiency. The application of the SHS method for welding refractory metals and materials, especially heterogeneous pairs, i.e. graphite-stainless steel, is most expedient.

For the elements of large-scale space construction in open space, the characteristics that determine the selection of structural material are density, strength, stiffness and the cost of delivery of the required material to the specified orbit. Alloys of magnesium with lithium are the lightest of those which may be obtained in space and used in various constructions. Although the lithium modulus of elasticity is very small, the Mg-Li alloys (containing up to 14 mass percentage of Li) have a slightly less modulus of elasticity than the modulus of Mg. If it is desirable to increase the cross-section area tenfold by using this alloy in a foamed state, then we will get the stiffness of a cross-section beam equivalent to the stiffness of a beam from continuous Al with a mass per unit of length five times greater, or the stiffness of a beam from foamed aluminium with a mass per unit of length greater by 1.6 times. The metals in foamed and sponge states in Earth conditions are manufactured by various methods, including the methods of powder metallurgy and by decomposing hydrides and carbonates of metals in the melts. It is obvious that because of the absence of notable gravitational forces, the methods of gas foaming, especially for large parts, may be realized in space more readily than on Earth.

For example, the following production flow diagram is possible. Under Earth conditions, we obtain compact blanks of alloy (Mg-14Li-Al), containing a foam-forming component of a barium hydride type, decomposing at heating with the liberation of a large quantity of gas. The compact solid blanks may be foamed in orbit by heating in a chamber whose inner size and shape provide the reception of a porous part with the specified sizes of the beam of a simple or complicated (for instance, trapezoidal) section.

The Kompozit Scientific and Production Association has proposed and started, jointly with the USSR Academy of Sciences, the preparation of an experiment to obtain porous materials and articles in space by the SHS method with the aim of developing the technology of further production of large-scale constructions with a low specific consumption of materials. However, it is still a long way to the erection work in space on a permanently operating orbital complex for the industrial manufacturing of products, although the interest in organizing such production is increasing, not only in Russia. For the aims of space production, the orbital space station in the USA (Freedom) and in the countries of Western Europe (Columbus, Euvrica) are at present under development, but the real possibilities of industrial production in space are as yet absent. The main barrier to the development of space technology is the irregularity and high cost of orbital flights.

The space station should be linked to Earth with a functionally reliable transport system. The progress of work on space technology is substantially hampered due to profit uncertainty sufficient for its investment pay-back. Practical information is presently being accumulated as to the advantages of obtaining products in space, which should demonstrate the economic expediency and commercial potential of production under weightless conditions.

In perspective, the economic efficiency of space production does not cause any doubts. Scientific studies and technological experiments carried out so far have permitted the accumulation of experience, the testing of techniques and development of infrastructure, representing a base for the commercialization of space technology. The arsenal of reliable rocket-carriers available in the Russian Federation minimizes the financial risk associated with a transport factor and already permits the start of pilot products in space.

The present, and approved, USSR Glavkosmos programme for developing the technology and production in space for the period 1990 to 1995 envisages the use, with a maximum possible pay-off, of the available spacecraft of the Photon, Mir-77KCT type and rocket-probes, as well as in the near future the creation and efficient use, from the commercial standpoint, of the orbital complexes NICKA-T, Lavochkin and TMII, which are specialized for space production.

However, the RF cosmonaut today faces the same crisis as the national economy of the country as a whole and the subsequent sharp reduction of budget allocations for carrying out space programmes has required the concentration of efforts towards the most promising directions of work in space production, so as to provide the development of base technologies to fabricate a number of particularly valuable materials in space. In addition, to finance some work on semiconducting materials, medical materials and biopreparations, organizations, authorities and branches of industry which are interested in the work are attracted. This factor is a main premise for the correct formation of the present concept of development of RF cosmonautics.

Figure 1. Production of materials:

1 - gallium arsenide; 2 - epitaxial silicon; 3 - biopreparations; 4 - zinc oxide, germanium, gradans; 5 - cadmium sulphide and telluride; 6 - mercury diiodide; 7 - Photon; 8 - Nicka-T; 9 - Lavochkin.

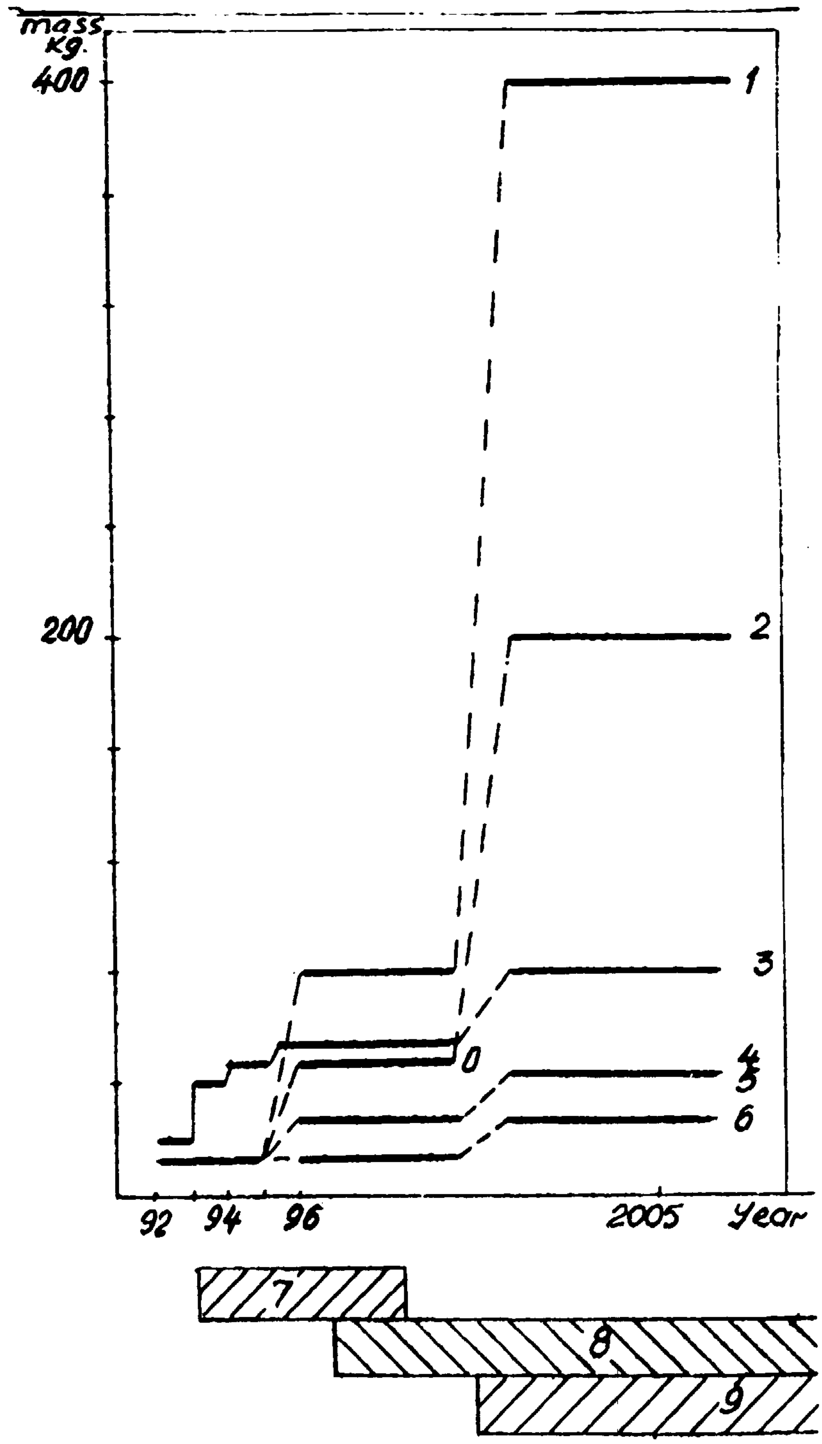

Figure 2. Conditions on spacecraft

Spacecraft	Power, kW	Acceleration, G	Lifetime, year	Returned mass, t	
				Net	Gross
Mir + 77KCT	2	10^{-2}-10^{-3}	2-3	0.02	0.03*
Photon	0.4	10^{-4}	0.04	0.03	0.05
Nicka-T	4-6	10^{-4}	0.4	0.05	0.1
Buram	up to 20	10^{-5}	0.1	0.3	0.5
Lavochkin	4.5	10^{-5}	2	0.02	0.5**
TMII	25-40	10^{-5}	5	1.0	2.0

* Per one flight of Sojuz spacecraft.

** Mass of production equipment and finished products.

Figure 3. Requirements placed upon spacecraft for space production

Material	Power, kW	Acceleration, G	Process length, h	Returned mass, t/year	
				Net	Gross
Complex semiconductors	7-15	10^{-4}-10^{-6}	up to 250	2	4
Silicon	100	10^{-5}-10^{-6}	up to 10	3	4.5
Biopreparations	0.5-5	10^{-3}-10^{-6}	up to 400	up to 0.002	0.5
Fundamental studies	0.5-1	up to 10^{-6}	up to 400	0.05	0.1

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3. NEW MATERIALS IN MEDICINE

by

Yuri G. Bushuev, V. N. Karpov and Yuri G. Shaposhnikov

The great medical and social significance of the problem of long tubular bone fractures stipulates a continuous attention of investigators on search of new more effective methods of medical treatment and shortening the periods for patients recovering therefrom.

During the last decades the new surgical treatment methods enabling the precise connection of bone fragmentation and their stability for a long period of time by application of the different fixtures for immersed osteosynthesis were developed.

A number of investigators have given great consideration to quantity and characteristics of the fixtures used, in order to determine their tendency to diminish such postoperative complications as slow-knitting, refractures and the formation of faulty joints.

The fixtures, made of co-alloys, which correspond in shape to complicated bone surface configuration and tightly fit to it are of advance type in that sense.

The structure of fixtures put over the bone for treatment of long tubular bone fractures designed and produced NPO by "Komposite" are the most available.

Design of plates which was carried out jointly with the Central Scientific and Research Institute of Traumatology and Orthopedy by N. N. Priorov and the Sibirian Department of the Russian Academy of Science was based on the following principal medical and technical requirements:

- The plates must withstand the loads on the extremities during normal activity without application of plaster immobilization;

- The degree of stability of fragments fixation must exclude the possibility of secondary displacements or fragments instability of some degree for all bones during the knitting period under functional load conditions.

The plates must be workable to production. To obtain this performance the metal plate of cylinder segment shape on the face of which there were holes to fix screws was put into the base of the structure. The plates and screws were made of biologically inert $Ti_6 6A_{14}V$ alloy .hat meets the requirements of international standard. Because of the complicated configuration of the bone surface, the cylindrical plate practically cannot be adapted to it and so the points of plate contact with the bone are arranged arbitrarily.

The base screws were used in the plate structure to take up the functional loads without bone failure.

The optimum forms of plates and holes and the number of screws were found by calculation and the high reliability and serviceability of items were confirmed by clinical tests.

Analysis of fixtures applied in international practice for osteosynthesis shows the most wide application for the metal fixtures made primarily of cobalt-base and titanium-base alloys or stainless steels.

However, these materials are characterized by the comparatively low level of strength performance, thus their rupture strength is 55-100 kgf/mm^2.

The serviceability and reliability of the most extremely loaded fixtures such as diaphysial plates in the above-mentioned materials for thigh and shin are achieved mainly at the expense of increase of item thickness that should be in the range of 5-7 mm.

Lowering the plate thickness down to 1-1.5 mm upon operating characteristics level maintenance should allow a significant decrease in the traumatism of surgical intervention and shorten the treatment period. Furthermore, the small thickness of the items accompanied by the rather high materials plasticity should allow the surgeon to simulate the design of the individual plate according to the patient's bone shape with the help of quite simple fixtures. Such a task has been solved on the basis of the development by the authors of the unique technology of cryogenic hardening of stainless steel, that makes it possible to improve strength properties by a factor of 3-4. As a result of this treatment the rupture strength level of 10X18H9 stainless steel rises from 50-55 kgf/mm^2 to 180-190 kgf/mm^2 and yield strength - from 35-38 kgf/mm^2 to 160-170 kgf/mm^2. The relative elongation is 8-10 per cent at rather high plasticity at the same time. The trial lot of diaphysical plates has been successfully tested in Professor Shapochnikov's clinic.

It was shown above that modern metallic structures ensure reliable fixation of bone fragments and eliminate the necessity for plaster immobilization and to load the operated extremity in the early stages. From that standpoint they received a high appraisal and there is no doubt of advisability of their use.

However, a lot of data about unfavourable influence of metallic implants on biological tissues are accumulated. Thus, a great difference of the metallic fixtures' and bones' properties often results in biochemical resorption of the latter but sometimes in repeated bone fracture. Stiff fixation of the fragments that completely eliminates loading of the regenerate has the negative effect on remodelling of knitting processes. Electrochemical activity of the metallic implants causes distortion and shunting of bone biopotentials and metallic ions storage in surrounding tissues. It affects bone activity in an unfavourable way. To remove the metallic fixture it is necessary to perform repeated surgical operations that often prove to be more difficult and traumatic than the initial one.

Because of the property differences between biological materials (blood, peritoneum, bone) and polymeric and ceramic materials etc. the fixtures produced by them are not ideal either. Having a high biocompatibility these materials, however, do not meet the strength and technology performance requirements for making modern structure materials.

The above confirms the necessity and importance of the working out and selection of new materials for fixture. In our opinion the advanced carbon-carbon composite materials are the most suitable for these purposes from the point of view of biomaterial science and biomechanics. By using the various technology modes and reinforcing fibre orientation in matrix and choosing the certain sequence of fibres having the different modulus of elasticity, one can design the materials with preset biomechanical properties.

Without opposing the osteosynthesis performed on the base of the structures in conventional materials to that of carbon-carbon composite materials, we found that the investigation of such materials and their use in accordance with reasonable recommendations will allow further progress in the field of traumatology and orthopaedics.

On the basis of a great variety of experiments the possibility of applying the carbon-carbon fixture for osteosynthesis in the case of long tubular bone fractures was studied.

The material properties were defined both in modelled medium and in living organisms. Sanitary and chemical toxicological, physical and biological properties of carbon-carbon composite material were studied by stand tests and experiments in rabbits and dogs.

Investigations of sanitary and hygienic properties demonstrated the opportunity of its clinical application. In all the cases the amount of substances given off by the carbon-carbon samples to modelled medium is 20 per cent less than that of carbon plastics adapted to usage.

The toxicological properties were estimated during experiments on biological test-objects which represented the cultures of skin fibroblasts and stromatic cells of human marrow. It was found that in the presence of samples of material under study, the growth and development of the used cell stems are not destroyed. Examination of the samples by scanning microscopy showed the fibroblast growth directly on the surface of the studied material.

The local and total reaction of animal organisms on studied carbon composite material implantation was investigated in experiments in rabbits to which the intramuscular inserts material were set. It was estimated that the material has no general toxicological influence on the animal organisms. The content of carbon particles in tissues adjoining the implant surface subjected to mechanical treatment appreciably exceeds that of tissues adjoining the untreated one. It confirms the advisability of the additional mechanical surface treatment of medical items produced of carbon-carbon composite materials.

The course of reparative regeneration of bone tissue in the presence of the carbon material samples was observed by the periosteum diaphysical defect model of radius in rabbits. It was found that presence of the carbon composite implant in the defect stimulates the processes of reparative osteogenesis. Thus, in sixty days the defect, in general, is filled with the mature bone regenerate.

Investigations of the structure-strength performance of carbon composite material following the sterilization and prolonged exposure in modelled medium or animal organism show the high stability of the material to influence the external medium factors. Moreover, the constancy of the material structure was established by X-ray structure analysis.

In stand tests of the bone-fixture system it was found that the strength of the carbon composite material plate is 85 per cent of that of the native bone. In addition, the stress-strain relationship curve for this system is similar to that of the native one. It meets the needs of modern biomechanics to a great extent.

It was established in experiments in dogs that during osteosynthesis of thigh fragments performed by the carbon composite plates on osteotomy and also on thigh multifragmental gunshot fracture the stable fixation of fragments, the healing of soft tissue and the recovery of functions of the operated extremity take place.

Medical and experimental research was the base for manufacture of trial lots of the carbon composite material fixtures recommended for clinical tests.

At present, the scientists pay great attention to development and study of bioactive materials on the basis of hydroxylapatite (HAP), carbon, callogens etc., as the most advanced ones for modern medical article production.

A great variety of methods of $Ca_{10}(PO_4)_6(OH)_2$ HAP synthesis is known. They can be, conditionally, divided into dry, wet and hydrothermal ones. Each of these methods has both advantages and disadvantages.

Dry methods, based on solid phase reaction are considered to be the most commonly used for production of HAP of accurate stoichiometry composition at the calcium/phosphorus ratio equal to 1:67, but they are protracted, carried out at high temperatures and, therefore, too power-intensive. It is difficult to reach the homogeneous composition by such methods. The HAP synthesis realized by $Ca_3(PO_4)_2/CaCO_3$, $Ca_2PO_7/CaCo_3$, $CaHPO_4.2H_2O/CaO$ mixes calcination at the 900-1300°C temperatures and in the wet steam presence may be examples of the dry methods.

Hydrothermal methods of synthesis include the reactions running at high pressures. It is connected with special equipment use. Hydrothermal synthesis uses the following reaction:

$$10CaCO_3 + 6(NH_4)_2HPO_4 + 2H_2O \dashrightarrow Ca_{10}(PO_4)_6(OH)_2 + 6(NH_4)_2CO_3 + 4H_2CO_3.$$

It should be noted that the $Ca_3(PO_4)_2$ tricalcium phosphate can be also formed at the same time. By the wet method it is possible to make both HAP as of stoichiometry composition, and the powder with calcium/phosphorus ratio lower than 1:67. The wet method based on precipitation reactions is implied as HAP precipitate production by mixing of water solutions of compounds, containing calcium and phosphorus ions on maintenance of the medium acidity index pH>7 and keeping the precipitate under corresponding conditions. In most cases $CaCl_2$, $Ca(NO_3)_2$, $Ca(OH)_2$ are used as a calcium source. H_3PO_4, NH_4H_2PO4, $(NH_4)_2HPO_4$ and, also, potassium and sodium phosphates are applied as a phosphorus source. To control the medium acidity index, the gaseous ammonia, ammonia hydroxide and sodium hydroxide are used frequently. The methods are characterized by formation of precipitate, corresponding to HAP composition in the initial process stage. Keeping this initial potassium phosphate precipitate under corresponding conditions results in a calcium/phosphorus ratio increase with HAP crystallization taking place. The rate of HAP formation by primary precipitate crystallization to HAP is a function of a large number of factors (the type and concentration of parent salts, the order and rate of mixing the medium acidity index, the reaction temperature, the keeping time, etc.) That is why, to receive the reproducible results, it is necessary to keep all the synthesis conditions correctly.

Among all the methods of hydroxylapatite synthesis the wet is the most preferable because of its simplicity to realize. It does not demand special equipment and high-temperature furnaces, but the control of precipitate formation is a necessary condition. Obtaining of HAP under laboratory conditions by mixing calcium nitrate with tri-substituted potassium phosphate is the most available wet method. The HAP synthesis method with application of water solutions of calcium chloride bi-substituted ammonium phosphate and ammonia as reagents was worked out. For this, the reactions described in the great majority of published patents were taken as the foundation:

$$10Ca(NO_3)_2 + 6(NH_4)_2HPO_4 + 8NH_4OH \dashrightarrow Ca_{10}(PO_4)_6(OH)_2 + 20\ NH_4NO_3;\ 10Ca(OH)_2 + 6H_3\ PO_4 \dashrightarrow Ca_{10}(PO_4)6\ (OH)_2 + 18H_2O.$$

Synthesized HAP represents fine-dispersed crystalline powder whose structures are similar to that of human bone and dental tissues.

The main performance of HAP is defined as the following:

Base substance content - 95-98 per cent

Calcium oxide content - 0 per cent

Tri-calcium phosphate content - 2-5 per cent

Impurities content, less than:

	%
Sulphate anion	0.003
Chlor	0.005
Ferrum	0.0002
Magnium	0.002
Arsenic	0.00006

Heavy metals, no more than 0.0005

The HAP particle specific surface is within the range from 20-100 m^2/g to 100-280 m^2/g and the particle size from 100-500 Å to 5-20μm.

HAP developed by the authors may be delivered in the form of powder, grains sized from 10-125 μm to 300-1000 μm particle water suspension, plates and pellets.

To define the possibility of HAP application in clinical practice a number of medical and experimental investigations were performed.

Lately, the influence of pharmacological substances and also up-to-date biomaterials on cell cultures was studied.

In practice the culture of any human cell can be both the mean and the object during the medical and biological investigations. One must not forget that the cell is the organism's elementary particle, the minimum volume of which possesses the properties characterizing the whole organism. Use of the cell cultures makes it possible to overcome a great variety of physical, physiological and biochemical limits caused by the organism's constitutional complexity.

To give the toxicological estimation of HAP the standard method of skin fibroblasts cultivation (the basis of the method of obtaining diaploid stems) and the method of cultivation of polyclonal diaploid stamms of marrow fibroblasts having the osteogenic properties worked out in the Gameleja Scientific and Research Institute of Academy of Medical Sciences of Russia were applied. As a result of tests carried out by the authors it was found that synthesized HAP is not cytotoxic. Moreover, the study of HAP ability to regenerate bone tissue was performed.

The toxicological investigations of HAP were conducted in two trial series. In the first series the reaction of tissues on hypodermic injection of samples was studied. It was found that in the early stage and during 90 days following implantation there is no inflammation around the samples. In the second trial series on implantation of the samples in rats a number of indexes of organisms' functional state was studied during 3 months: dynamics of body weight, composition of peripheral blood, workability, state of the central nervous system, liver and kidney functions. By the time it was fixed, noticeable deflections of the above-mentioned indexes were not observed (according to statistics done between 2 weeks and 1-3 months).

On the basis of performed toxicological tests it was shown that HAP has a perfect compatibility with the organism's tissues. It has no irritating, allergic or general toxic effect on the organisms of animals.

Research of HAP osteogenic properties is realized in experiments in 40 six-month-old rabbits of the chinchilla kind by 2.5 cm resection modelling of radius diaphysis. To conduct the investigation, lyophilized sponges produced of modified collagen were prepared into which gentamizine (0.125 g) and HAP powder in 1:5 ratio was added. In control series the defects on bone resection were not replaced and the tissues over them were connected completely. In the other ones the studied material was implanted to the defects. The experiments in animals were stopped in 30, 60, 90 and 120 days. On killing the animals X-radiography of the studied bones was performed with subsequent histological agent preparation for light microscopy. The results were estimated visually and densiometrically from presence of regeneration signs in the X-ray pattern and qualitatively from histological agents. The results are obtained as follows: there were no signs of regeneration in any case in the control series (without defect replacement). Resected surfaces of the radius within 60, 90 and 120 days were covered with tip plates. The defect is partly filled with bone reagent moving from the side of the resected surfaces of the radius adjoining to the defect of the ulna. Within 60 days of HAP implantation, in three cases out of five, the regeneration signs were discovered with regenerator content not exceeding 45-60 per cent. In the control series the defect is not filled with the bone reagent while HAP implantation cuts down defect size. Between 90 and 120 days the pronounced osteogeny of the great majority of animals is revealed. Moreover, the character and body of the regenerator in these trial series was similar.

Thus, on the basis of medical and experimental investigation the following conclusion can be made: the developed HAP has perfect biocompatibility with the human organism, does not provoke immunoconflicting reactions and shows osteogenic activity. HAP is recommended for production of implants when surgically treating bone-destructive diseases, for the manufacture of endoprostheses of joints as bioactive coating, for medical treatment on destroyed skull bones resection and other elements of bone skeleton, bone cysts, osteomyelitis, etc.

The problem of adoption of new material in the practice of medicine is connected with a number of solutions to key science capacity tasks.

The vascular repair operations performed utilizing prostheses represent the majority of all vascular surgery operations. World wide, approximately 2.5 million varied operations are carried out yearly, using blood vascular prosthesis. The commercial production of prostheses of various types mainly in synthetic fabrics has been launched by many corporations. In Russia, on the basis of data obtained by the Bakulev Cardiovascular Surgery Institute of the Russian Academy of Medical Science, annual demand for the blood vascular prostheses is 180-200 thousand pieces. A large clinical experience of blood vascular prostheses applications showed that in the early post-operative period in 6-8 per cent of cases embolism of prosthesis begins due to thrombosis formation on the surface. Thus, one of the main problems is the making of artificial blood vessels having increased stability to thrombus formation.

In our opinion, there are three general directions to the solution of this task today:

- Vascular prosthesis surface modification, based on immobilization of the heteropolymeric conjugations of biologically active substances;

- Creation of porous tissue by means of a special treatment of polymeric film;

- Development of carbon-containing vascular prostheses.

There are several variations of problem realization by the first method. One of them, based on the heparinization principle, was developed by the polymer laboratory of Bakulev in clinical trials.

In accordance with the realization of the second direction, Core-Tex (USA) produced prosthesis made of expanded polytetrafluoroethylene.

These prostheses were favourably received by vascular surgeons. Vascular prostheses fabricated of carbon materials were developed by scientists in a number of countries, including Russia. On the basis of domestic developments performed by NPO "Komposite" in cooperation with the Elementorganic Compounds Institute of the Russian Academy of Sciences and Moscow State University, a new unique material was developed, which proved to be a previously unknown allotropical carbon modification of linear structure.

Its name was derived from the Latin "Carboneum", meaning carbon with the "ine" ending, adopted by organic chemistry for C≡C triple bond designation. Interest in this material was generated by the fact that blood vascular prostheses produced on this basis have high stability to thrombus formation compared to that of conventional materials used for vascular prostheses production.

Methods of production of medical articles with carbine covering are based on the processes of polyvinylidene halides chemical carbonization. During the treatment of polyvinylidene halides, in particular, of polyvinylidene fluoride with strong bases, for example, alkalis, the reaction of dehydrohalogenation proceeds on the surface of the treated article resulting in the formation of the required thickness carbine layer possessing the high stability to thrombus formation and fine compatibility.

As a rule, the carbonization process runs at room temperature effected by a mixture of alcohol solution and acetone on fibre yarn or finished prostheses. The results of chemical analysis of carbon surface film showed the carbon content equal to 93 per cent and of fluor content equal to 7 per cent. Control of dehydrofluoration process was performed by IR-spectroscopy method.

The most informative and convincing data of the linear carbon were obtained by Guseva M. B. in MSU on the basis of its electronic structure research by Auger-spectroscopy and characteristic energy losses spectroscopy (CELS).

Since the probability of the Auger process depends on energy of electrons of carbon materials valency zone, it is possible to obtain the complete information on electronic structure of carbons valency zone by the energy spectrum of Auger-electrons. It is seen that all the features of predicted results for one-dimensional carbon are reflected by the experimental curve: positions of peaks of electronic state density correspond to E_1 = 12.5 eV, E_2 = 16.5 eV, E_3 = 19-20 eV, E_4 = 25.5 eV energies.

The E_3 = 19-20 eV and E_4 = 25.5 eV peaks are connected with the ceiling and the bottom of δ-zone carbon chains. The upper part of valency zone (E<17) corresponds to π-subzone of carbon chain. It arranged much deeper than π-zone in graphite. The fall-through between the δ and π-subzones is affected by the atoms number in the chain and decreases when the chain length increases (the N number of atoms).

The function of characteristic electron losses in carbine S(E) and the imaginary (e_2) and real (e_1) parts of dielectric constant are presented. They are estimated on the base of this function in accordance with Cramers-Croning theorem. The imaginary part of the dielectric constant, being the function of energy losses, characterizes the energy spectrum of single-partial electron excitations. As is seen, the density of single-partial electron transition achieves its peak value at energies of E_1 = eV; E_2 = 7.8 eV; E_3 = 9.9 eV. The fragment of energy structure of one-dimensional carbon chain with sp-cross links between atoms is also shown in accordance with scheme of the following zones: two δ-zones (linking and anti-linking states) and π-zone. Because of Pierls or Motta-Huffard transitions (presented in one-dimensional systems) π-zone should be broken down into two subzones with forming the fall-through equal to 1-2 eV. Thus, electron excitations with energy of 1 eV can be related with π-zone transition between the states separated with the fall-through.

The real part of e_1(E) the collective plasma oscillations (plasmon) can take place but for this it is necessary for the density of interzone transitions (e_2(E)<1) to be low. It is clear, that at energy values equal to 4.....5 eV the real part e_1 is equal to 0 and imaginary part e_2 is < 1. It means that at such energy the excited electrons of π-zone behave as free ones and the relative peak of S(E) is explained by collective excitation of electrons. The π-plasmon energy greatly exceeds that of graphite and is close to that of a one-dimensional polyacetylene chain. It is also in accordance with the conclusion about carbon linear-chain structure. The energy of the second peak (8 eV) coincides with energy of transition from locking δ-zone into an anti-locking one at K = ±π/a. The third peak e_2 at E = 9.9 eV is caused by transitions from π-subzone bottom into anti-baking δ-subzone at K = 0.

Thus, analysis of the spectrum of carbine characteristic losses related with single-partial interzone transition also completely confirms the conclusions about carbine chain structure investigated by Auger-spectroscopy. Moreover, they are in agreement with the theoretical prediction about π-zone breakdown and "metal-semiconductor" transition that takes place in one-dimensional systems.

On the basis of electron-spectroscopy investigations one can deduce that carbine has a linear-chain structure and semiconductor properties.

Up to the present the large-sized carbine monocrystals have not been produced: it occurs in nature in the form of fine-dispersed impurities. The synthesis is used for production of amorphous carbine mainly, or also of dispersed polycrystal ones. Its crystalline structure was investigated by methods of high-voltage electron microscopy obtaining the microdiffraction pattern of single microcyrstals.

The point electron diffraction pattern represents the basal plane of reciprocal lattice of the hexagonal system crystal. On the basis of the diffraction pattern it was found that the elemental carbine cell consists of three 6-atomic chains disposed along ribs of the hexagonal cell and one chain in the centre of the cell. The rib sizes of the hexagonal cell for the α-carbine chains of polyine type are defined as the following: a=b=5,08 A, c=7,8 A. The distance between chains - R=2,95 A. Each chain consists of six atoms. For the cumulene type of β-carbine crystals the sizes are defined as follows: a=b=4,75 A, c=2,38 A. Each chain of cumulene consists of two atoms. The predicted density of β-carbine is equal to 3.31 g/cm. Such a model gives the correct location of point diffraction reflections.

The hypothesis of periodically located turns of carbon chains is made. It explains the meaning of parameter "c" (the double length of chain linear fragment) and to relate the change of elemental parameters with the size of linear section between the turns.

The investigation conducted on the electron structure of carbine films in which lattice parameters vary over a wide range confirms the hypothesis of chain linear section change.

Processing of diffraction data on the basis of Peterson's function (the method is widely used in X-radiography) makes it possible to get the information about potential distribution in the crystal. On the basis of these data it was advantageous to construct the structural model that is adequate to the diffraction pattern of carbine of the most spreading modification.

The electron clouds are p-orbitals of carbon atoms. There is an sp-bond carbon chain at every corner of the hexagon. It determines the above-mentioned potential distribution. There is another chain near each corner. It is displaced relative to the corner chain by the third part of the translation vector. But the direction of displacement did not quite coincide with the translation vector and is distinguished from it by 2. The distance between these chains is 1.49 Å. The length of the hexagon ribs is 2.97 Å. There is a chain in the centre of the hexagon as in the first model.

In addition, in essence the new detail is revealed: the atom bound with carbon chain by chemical way was observed near the hexagon corner chains.

Study of the carbine crystals' chemical composition by Auger-spectroscopy revealed chlor presence. The foreign atoms detected by potential distribution may be interpreted as chlor atoms bound to carbon chains by chemical way. It provides the stability of chain turn. The results show that carbine turns are formed owing just to impurity in contrast to the accepted earlier point of view according to which formation of turns in the carbine chain is accompanied by the advent of broken links. With their help the chain is united into the crystal.

The promising results of carbine utilization for production of artificial blood vasculums were shown by medical research. It was revealed that their stability to thrombus formation is significantly higher than that of materials used in the vascular prostheses structure.

Also we studied the possibilities of utilizing the carbine coatings with the metal joint endoprostheses as biocompatible ones.

Carbine coatings were derived by the method of dehydrohalogenation of polyvinylidenhalogens applied to the bitanium prosthesis surface.

The process of coating production was similar for all samples and consisted in the following:

- The polyvinylidenfluoride spraying on the titanium plates, heated to 130°C;

- The coating carbonization was performed in the alcohol solution of alkaline (KOH) and acetone at room temperature;

- The obtained carbine coating was heated in air for 30 minutes at 130°C.

The described method of coating application ensured uniform thickness and an unruffled layer. Morphology study by electronic microscopy showed the middle size of non-uniformities on the surface not exceeding 1 m.

The chemical composition investigations by the X-ray microanalysis method demonstrated a good chemical composition uniformity over the coating surface. The carbon content in all films is no less than 90 per cent; both fluorine and oxygen contents are no more than 5 per cent. The preliminary treatment mode of the plates' surface determines the high quality of coating bonding with surface.

The prepared coating was studied by infrared spectroscopy. The investigations revealed the wide absorption band of 1,000-1,800 cm^{-1} as a result of the dehydrogenation process. This band corresponds to the non-symmetric oscillations of the cumulene chain with deformation period along the chain equal to 4 carbon atoms. The symmetric oscillations along the chain, corresponding to the 1,900-2,100 cm^{-1} absorption band were not exhibited because of their faint activity in IR-area. The combination scattering spectra of this sample has 1,900-2,000 cm^{-1} absorption band corresponding to symmetric oscillation of the cumulene chain. These results give evidence of formation of perfect carbine chains by the described method. The carbine coatings' biocompatibility was evaluated by growing polyclonal diaploid stems of marrow fibroblasts possessing osteogenic properties.

The results of investigations showed the absence of cytotoxicity and good biocompatibility of carbine with bone tissue.

The area of carbine application in medical practice may be significantly expanded owing to the unique properties of this material. Beside their application in items for cardiovascular surgery, traumatology and orthopaedics it is proposed to use the carbine in the prostheses of urea and bile passages, food passages and as a stitch material.

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4. APPLICATIONS

A big boost for US-Soviet ventures

Indeed, it has blasted all the way into space, as the first US experiment to fly on the Soviet space station Mir shot into orbit in 1989. A protein crystallization package - designed by Payload Systems (Cambridge, Massachusetts, USA), a unit of Space Industries International Inc. - will be in space for more than two months. The long duration is necessary to grow large, homogeneous protein crystals for generating X-ray-diffraction data.

Such information is useful for developing products for the pharmaceutical, biotechnology, chemical and metallurgical industries, says Anthony Arrott, Payload's president. The Mir station is the only manned facility offering extended time in microgravity - the US's Space Shuttle is typically aloft for seven to ten days, not enough time for many proteins to crystallize. (Source: *Chemical Engineering*, January 1990)

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Under the 1987 agreement, the US and the Soviets are working on 16 joint projects covering five areas: solar system exploration, space biology and medicine, space astronomy and astrophysics, solar-terrestrial physics, and Earth sciences. Added in 1988 were exchange of scientific instrument flights on each other's spacecraft, and exchange of results from studies of unmanned solar system exploration missions. (Extracted from *CBEN*, 12 August 1991)

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Italian firm to participate in Soviet space experiments

Kayser Italia of Leghorn is working on two contracts awarded by ESA's (European Space Agency) ESTEC [European Space Research and Technology Centre] centre. The contracts involve the development of sophisticated electronic equipment for experiments to be carried on board Soviet satellites. In 1990 a meeting took place - partly at the Soviet Institute of Biology's (IBMP) laboratories and partly in Kayser's Moscow offices - between a Soviet and an ESA delegation to define the scientific and technical aspects of the Bion 10 mission, which is scheduled for launching in 1992.

Both of the two contracts awarded to the Leghorn-based company involve biology experiments. The first, called Biopan, focuses on the development of a container of biological samples to be installed outside the Soviet satellite. Once the satellite is in orbit the container will be opened to expose the samples and will be closed prior to the capsule's re-entry into the atmosphere. Kayser Italia's responsibility under this project will be the development of the data acquisition system. The second experiment is called Biobox and consists of an incubator containing biological samples to be installed on board a Soviet Photon satellite. The contract awarded to Kayser Italia involves the "phase B" of the entire electronic feed, control, monitoring, and data acquisition system as well as the satellite's electrical interfaces. (Source: *Spazio Informazioni*, 17-24 October 1990)

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AUSTROMIR joint Austro-Soviet space programme

Fanak Data Processing-FDP and NOVA Aerospace, privately owned companies registered in Vienna, Austria

FDP successfully contributed the joint Austro-Soviet Space Programme "AUSTROMIR", having been responsible for the technical project management of the two large medical space-flight experiments "MOTOMIR" and "MONIMIR". As a result of this participation, FDP gained unique experience in managing complex manned-space projects involving Austrian and Russian authorities, engineers and scientists.

In order to meet the increasing demands for such expertise, FDP established a specialist subsidiary company, NOVA, to take over responsibility for all aerospace business. NOVA's key-personnel consists of engineers from aerospace and related fields, who have gained their considerable experience through their direct involvement in projects of the European Space Agency.

NOVA Aerospace

General agent for Glavkosmos and for the Institute for Bio-Medical Problems (IBMP): As a consequence of successful cooperation with Russian institutions during AUSTROMIR, NOVA has been selected as General Agent for Glavkosmos in Austria and for IBMP in Austria and Germany. Nova Aerospace executes, coordinates and supports projects and studies involving Russian institutions, companies and specialists as expert consultants, sub-contractors or suppliers.

Medical applications (space and non-space): As a founding member of the Austrian Society for Aerospace Medicine/Life Sciences, NOVA is supported by scientific consultants from Austria, as well as from Russia and Germany, and are therefore in a position to contribute expert knowledge to technical and scientific projects and studies in the field of medicine and medical research and technology.

Space hardware: Due to well-established partnerships in science and precision manufacturing industries, NOVA is in a position to design, develop and manufacture hardware in the following space engineering fields: microgravity and life support systems; scientific instrumentation and payloads; satellite units and instrumentation; ground support and test equipment.

Product assurance (PA): The PA-team has gained its experience through working with ESA and related high-technology industries. NOVA is therefore able to provide support to the development, implementation and application of procedures in the following areas: reliability, availability, maintainability, safety (RAMS), risk assessment (quantitative and qualitative), reliability centred maintenance (RCM), quality assurance standards (e.g. ISO 9000); configuration management systems.

FANAK data processing

Software development and engineering: Key personnel, recruited from major software houses, have substantial expertise in the development, engineering and implementation of software and are able to support such areas as: ground and on-board software; relational database systems (SQL); instrument control software; data evaluation software for scientific experiments; simulations; real-time processing; image processing; graphic visualizations; advanced numeric and analytical applications; local area networks; "tailor-made" soft- and hardware solutions.

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Austrian "MIR" experiments

Experiment: LOGION

Objectives: Test of ion emitters, used to prevent electrostatic charging of space vehicles.

Applications: Preventing static charges building up on satellites, space stations and probes.

LOGION - Operation of a liquid metal ion emitter module under microgravity

Austrian Research Centre Seibersdorf, Department for Physics

The experiment LOGION was flown on the space station MIR in the framework of project AUSTROMIR. The aim of the experiment was to test a liquid metal field ion emitter (LMIS) under microgravity conditions. The experiment consisted of an ion emitter module with three liquid indium emitters and an integrated ion collector. This assembly was mounted in a hermetic ion-pumped vacuum system. Electronic control and data acquisition units were mounted outside this vacuum system.

The experiment was operated without problems and first data were obtained via telemetry. The data showed that values for operational parameters of the LMIS under microgravity were within the range measured on ground with minor differences in power consumption of the emitters. The results are valuable for optimizing software control of similar emitter modules to be flown on the CLUSTER project.

PUBLICATIONS

F. G. Rüdenauer, W. Riedler, V. Berzhatyi, M. Fehringer, E. Göschl, C. Kropiunig, L. Neznamova, W. Steiger, K. Torkar:

LOGION: Operation of a Liquid Metal Ion Emitter Module Under Microgravity. Proc. European ISY 92 Conf.: COSY-8 Symposium, ESA-SP 350, in press, 1992.

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Experiment: MIGMAS/A

Objectives: Testing a scanning ion microscope for material analysis under space conditions.

Applications: Future use, e.g. in the diagnosis of material changes brought about by "space corrosion" in space vehicles and stations.

MIGMAS/A - Test of a Scanning Ion Microscope Onboard the Space Station MIR

Austrian Research Centre Seibersdorf, Department for Physics.

MIGMAS/A is a scanning ion microscope for topographical investigation of material samples. The main components are: (a) a scanning ion gun using a liquid metal indium ion emitter and an electrostatic focusing lens, mounted in a vacuum system; (b) electronic control and data storage; (c) image display and processing of scanning ion images.

During the AUSTROMIR mission, the experiment performed completely up to specifications. Stability and image resolution were identical to the values measured on ground. It was shown that a highly complex analytical instrument can be brought into orbit without degradation, that it can be operated there by a cosmonaut without any problems and that complex analytical imaging data can be transferred to ground without loss of information.

PUBLICATIONS

W. Riedler, F. G. Rüdenauer, P. Beck, V. Berzhatyi, M. Fehringer, R. Finsterbusch, L. Neznamova, R. Pammer, F. Pürstl, W. Steiger: MIGMAS/A: Test of a Scanning Ion Microscope Onboard the Soviet Space Station MIR.Proc. European ISY 92 Conf.: COSY-8 Symposium, ESA-SP 350, in press, 1992. (Source: *Österreichische Raumfahrt- und Systemtechnik Gesellschaft MBH, Operngasse 20C, A-1040 Vienna, Austria. FAX: 0043/1/58814-221*)

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5. MARKETING

The Baikonur Cosmodrome in the Soviet Union has become a commercial concern known as International Spaceport, offering the launch services of Proton, Soyuz, Zenit and Energia boosters.

International Spaceport is a joint stock company founded by the Kazakhstan Space Research Agency, commercial banks and the space associations of the Russia and Ukraine federations.

These founding organizations own 80 per cent of the shares; the other 20 per cent will be offered to private investors willing to assist in the establishment and activities of the Spaceport.

Sergei Sopov of the Kazakh space agency says that it will "...compete with Arianespace, the USA and China" in the satellite-launcher market. (Source: *Flt Intnl*, 26 November 1991)

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Is space research paying off?

While space technology payoffs are not always apparent, it does produce revenues. The annual yield from the use of satellite photos of Earth totals about one billion roubles in the Soviet Union. These photos are used in prospecting, agriculture, forestry, water conservation, and fishery. They have helped improve prospecting while reducing the cost of surveying by nearly 20 per cent. Generally, space map-making and probing natural resources are among the most highly profitable operations. It has been estimated that the use of earth satellites for weather photography saves from 500 to 700 million roubles a year.

Of course, not all achievements in space research can be illustrated by income or another effect in terms of money. Nor do we know exactly the amount of profit to come from the operation of instruments running on monocrystals of lead sulphide. Such monocrystals perfect in their qualities are impossible to grow on Earth. Specialists estimate that the output of semiconducting and other materials, drugs and biopreparations by the Soviet space industry is to reach three to five billion roubles a year in 1995.

The economic effectiveness of communications satellites deserves special mention. The importance of a business contact by radio telephone between partners, say, 10,000 km apart, is clear to everybody, considering that nowadays broadcasting and communications via earth satellites are used not only for entertainment, but also perform serious economic functions.

Income from the satellite navigational system does not lend itself to exact calculating either. About 4,500 ships are now fitted out with navigational receiving equipment. That makes it possible to reduce transportation costs and enhance the safety of navigation.

The crew of A. Solovyov and A. Balandin on board the *Mir* station was the first cost-accounting expedition to outer space. The net income from the crystals and drugs made in weightlessness is estimated at 25 million roubles. Besides, the direct effect for which the specific satellites, spacecraft, orbital stations, and booster rockets were made, there are also other "items of revenue" from space flight.

Firstly, it is the economic gain from the dissemination of advanced experience, technologies, materials, and items in the various sectors of the national economy (this process is called "spinoff" in other countries).

Secondly, it is the parallel or complementary manufacture of civilian products at enterprises making space rocketry and its equipment (diversification).

And finally, thirdly, it is a change in the specialization of the factories making various elements of space hardware to get them to manufacture civilian goods. As a matter of fact, the latter is called conversion.

Let us now consider in greater detail how space research benefits ordinary human beings. We have established that it exerts a stimulating influence on other types of technology far removed from space uses. This is because the makers of earth satellites and orbital stations, adapting them for operation in tough conditions (sharp temperature fluctuations, vacuum, weightlessness, radiation, and overloads), are compelled to invent new promising materials, structures, instruments, and manufacturing methods. An item for use in outer space must be light (it will have to fly into outer space), reliable (there are no repair shops there), highly automatized and self-contained (man cannot always be by its side and his possibilities are not unlimited either), and highly efficient (the launch of a satellite and its control cost millions of roubles, dollars or francs). Engineers have to fight heavy "battles" for saving every gram of mass, every Watt of electric power. And if we come across miniature and power-saving radio transmitters or electric air valves for a satellite, you should know that yet another victory has been scored in those "battles".

And if down-to-earth items are made in the "space" fashion, they become useful in man's economic activity. It so happens that many space instruments, machine parts and mechanisms find their work on Earth without any major overhaul. Some of them are marked by high resistance to heat, cold, and radiation. The

Soviet Union's well-known self-propelled lunar vehicles or Moon rovers made a good account of themselves in clearing radioactive debris after the accident at the Chernobyl nuclear power station.

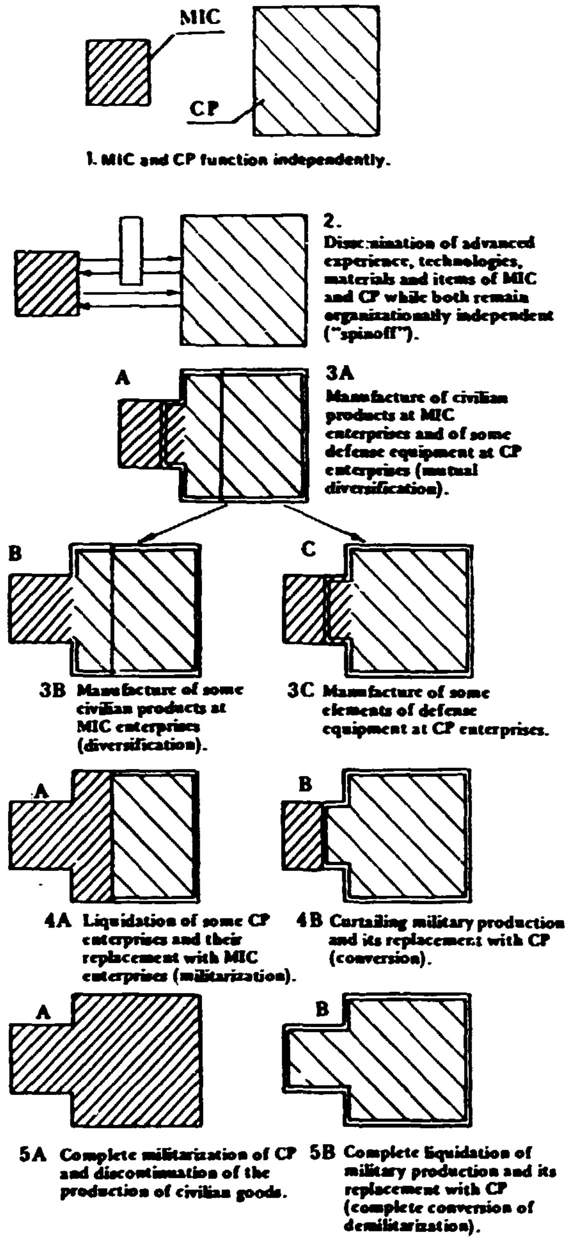
Much of what has been made in the space industry was put into practice elsewhere, in the construction, steel, ship-building, electric engineering, instrument-making, and medical equipment industries. Throughout three decades a number of departments has been using information and the first experimental samples of products from the space rocket complex without paying anything for them and even without taking stock. For example, among those which left the space industry to join civilian production are new technologies for manufacturing heat resistant and heat insulation materials, heat-resistant coatings, foam plastics, glass-reinforced plastics, special sealants, binders and glues, welding and soldering techniques, and the method of making light-reflecting coatings. And big headway was made by all of them.

According to the General Designer of the Energiya Research and Production Association, the technique of making heat-resistant insulation coatings for wires and cables with a working temperature of 300 to 900°C and corrosion-proof and flame-retardant coatings in an oxygen medium has been introduced at more than 500 enterprises of 11 ministries. That made it possible to prolong the service life of electric hoisting and braking mechanisms, electromagnetic rollers, rolling mills, electromagnetic pumps for melted zinc, and induction heaters.

The opportunities opened during the making of the *Energiya-Buran* system deserve special mention. The developers maintain that about 600 new technological suggestions have been prepared for introducing them into the national economy. These include control systems, electronic devices, radio engineering equipment, and electric devices; structural and heat-insulation materials; techniques and technological equipment; testing benches and cryogenic (low-temperature applied to liquid oxygen and hydrogen) complexes, aircraft automatic landing devices, specialized ground vehicles, and hoisting and loading mechanisms. The introduction of structural materials alone will earn about 1 billion roubles. For example, alloy 1201 was developed for the hydrogen and oxygen tanks of the *Energiya* rocket. It is twice or even three times more durable than chrome and nickel steel and lighter, too. That and other cryogenic alloys, if used in mechanisms operating in the Far North, are expected to prolong the service life of machines threefold. No one will refuse to use paint primer EP-0214 either. It reliably protects steel from corrosion and retains elasticity at temperatures from 253°C below zero to 200°C above zero. The antistatic heat-regulating coating as well as current-conducting (heating) and nonflammable coating AK-5260.

Is Space Research Paying off?

Versions of connections between the military-industrial complex (MIC) and civilian production (CP).



Nearly 2,000 parts of the *Buran* spaceship have been adapted for operation without oil or grease in the conditions of dry friction. They are made of nickel and titanium steel alloys. But it is the coating that matters. It is both antifriction and wear-resistant. Many other new materials (they number about 50 types) are also unique in their qualities and manufacturing techniques. And they are sure to find wide application in the national economy. The material of which space heat-protection tiles are made is already used for the heat insulation of high-temperature furnaces which saves 30 to 50 per cent of electricity in smelting. Works are under way to introduce such ceramics into automobile engines and high-temperature filters for aggressive media.

The use of a carbon-based composite in the national economy also opens ample opportunities. It is of that composite that the tip of the *Buran* wing is made. This material will be used to make heaters for electric furnaces, crucibles for smelting refractory metals, and substitutes for various parts of the human skeleton (it possesses an absolute compatibility with living tissues).

The Deputy Chief Designer of the *Energiya* rocket once observed that hundreds of new sensors, transformers, thermometers, vibration gauges, equipment, and software for handling large flows of information had been made in developing that powerful booster. Such sectors as the machine-building, and power industries, using the above-mentioned instruments to diagnose the state of technical facilities can raise their reliability and efficiency without spending time or money on their own research.

And if we consider that the items, materials, technological efficiency, production capacities, and theoretical and methodical stock created and used in the space industry will be used in the civilian sectors in full measure, space research will fully pay off by 1995 provided the present level of spending is maintained.

However, the changeover to the market economy is sure to block the road to the waste of progressive achievements in the national economy, rule out their loss and oblivion. Space flight should and will bring in commercial profit.

At the same time space flight can yield profit even if its technology is used in its own field. (Extracted from *Science in the USSR*, 1991, No.2, Article by A. Yevich)

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6. PUBLICATIONS

Materials Processing in the Reduced Gravity Environment of Space

Edited by R. H. Dorc· us and P. C. Nordine, Materials Research Society, McKnight Road, Pittsburgh, PA, USA, Symposia Proceedings, Vol. 87, 1987

The book is the proceedings of a meeting held by the Materials Research Society in Boston, Massachusetts in December 1986.

The 42 papers collected in the proceedings cover a large spectrum of the microgravity sciences including the fluid dynamics of droplets related to biomedical research. The majority of the papers are otherwise oriented towards materials science issues including solidification processes, eutectic alloys, semiconductor and protein crystallization and glass processing.

The second large contribution of papers in the book is from fluid physics. Papers on the influences of convection in solicitation processes, space furnaces as well as in bubbles and droplets present a good overview of this microgravity science sector.

The volume also contains a set of papers on the commercialization aspects of microgravity. The one by Battelle Institute presents a good overview of the potentially economically viable products that can be processed in a low gravity environment.

This book presents a good summary of the state of the art in microgravity science circa 1987. Because of the shuttle accident and the large proportion of experimental papers presented, the proceedings are still of interest to graduate students and to microgravity scientists looking for a technically oriented survey of microgravity sciences.

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"Australian Space Activities to the Year 2000"

This was the theme of the 1991 seminar series organized by the CSIRO Office of Space Science and Applications. As foreshadowed at the time, the Office has now published in book form the texts of the 13 presentations made during the series. These give up-to-date, specialist overviews of current Australian space activities in diverse fields, together with a measure of speculation on where the national effort might best be directed from now until the turn of the century.

The new book is essential reading for all those involved in or associated with space and space-related activities. Copies are available from the CSIRO Office of Space Science and Applications, GPO Box 3023, Canberra, ACT 2601, Australia, Fax: (06) 279-0812, for $A15 each, including postage. Please make cheques payable to the CSIRO Receiver of Monies.

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1991-1992 SAE Aerospace Sources and Suppliers Directory

Society of Automotive Engineers Inc., 1991, 300 pp. (Order No. ASD-91, $49)

Directory identifies sources of products and materials specified in SAE Aerospace Standards (AS), Aerospace Information Reports (AIR), Aerospace Recommended Practices (ARP), and Aerospace Material Specifications (AMS). New to this edition is a section that cross-references AMS specs, government (federal and military) specs, and UNS numbers.

Order from: SAE Customer Service, Dept. 2420, 400 Commonwealth Dr., Warrendale, Pa. 15096-0001, USA; Tel.: 412/774-4970; Fax: 412/776-0790.

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Aerospace Technology Centres

Essex: Longman, 1988. 194 p. $245, 629.1'072 ISBN 0-582-01773-4

Contents: From Argentina to Zimbabwe. Subject index.

Note: An international directory arranged geographically by country. Includes over 700 aerospace related research and technology laboratories in the public and private sectors. Entries include title, address, telephone, telex, facsimile, parent, product range, names of senior staff, number of R&D staff, annual expenditure, activities, publications, and client organization (when available). Includes a helpful subject index as well as establishment index. A good reference for science and technology collections.

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Advanced Materials in Aerospace Applications 1990-1991

Advanced Materials in Aerospace Applications 1990-1991 is a follow-up report to the initial one in the series - Advanced Materials in Aerospace Applications 1989. The latest report examines the activities of over 700 organizations working on developing materials for military and commercial aircraft, spacecraft and satellites. The vehicles themselves and their component parts are tabulated by company and by type of material. The R&D solutions to the problems faced in these applications are also categorized by company and by material. Over 1,000 studies are tabulated, profiled and summarized in the report.

Advanced Materials in Aerospace Applications 1990-1991

Coverage:	January 1990 to July 1991
Size:	1,100 reports, 500 pages, 6 sections, loose-leaf format
Other features:	Diskette database, company address list
Price:	£190 (UK)/US$ 325 (USA and other countries)

(ASM International, Materials Park, Ohio 44073-0002, USA)

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Journal of Aerospace Composites: New bi-monthly technical trade magazine will serve engineers, scientists and managers involved in the design and manufacture of products utilizing composite materials by presenting technical articles written by top composites engineers, and information prepared by experienced engineering and technology editors. Cardiff publishing company, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111; (303) 220-0600.

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Metallurgical Assessment of Spacecraft Parts and Materials *by B. Dunn*

This book presents the science of metallurgy and metallography and demonstrates how they can be applied as an integral part of spacecraft product assurance schemes which involve quality, material and process evaluations and the selection of mechanical and component parts. Detailed case studies, methods of evaluation and equipment are included, together with micrographs and fractographs, to highlight the engineering problems associated with critical mechanical and electronic devices. Welding, brazing and soldering processes are also discussed, as in-depth metallurgical analyses uncover shortcomings inherent in the materials, the design, or induced by incorrect processing parameters. This book will also be of value to engineers not connected with the space industry. *1989/363 p. Price: £59.50. (Technical Standards Services Ltd., Blakes House, 98 Ickleford Road, Hitchin, Herts. SG5 1TL, UK. Fax: (0462) 45 77 14)*

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Superplasticity in Aerospace

Edited by H. Charles Heikkenen and Terry R. McNelly, The Metallurgical Society, 420 Commonwealth Drive, Warrendale, PA 15086, USA, 1988, 373 pp. hardcover

Superplasticity is defined as the ability of certain materials to undergo extensive plastic deformation, often in the absence of necking, prior to final failure. Despite the fact that one can find reference to superplastic behaviour in the literature as far back as the 1900s, study of this phenomenon has been concentrated over the last 25 years. Modern study of superplasticity has evolved from model systems, such as Zn-22%Al, to encompass Al-Li alloys, Al-Mg alloys, mechanically alloyed Al alloys, high strength Al alloys (i.e. 7XXX), microduplex stainless steels, high carbon steels, metal matrix composites (MMCs), as well as ceramic matrix composites ($MgAl_2O_4/Al_2O_3$). The shift towards systems of commercial significance has been fuelled by the keen interest developed by the aerospace and other industries in using the superplastic forming for the economical manufacture of otherwise extremely difficult-to-form materials.

There are 21 papers included in this collected work, which is well organized into four chapters:

Superplastic Deformation Mechanisms
Superplastic Deformation Mechanisms
Superplastic Al-Li Alloys, and
Superplastic Aerospace Applications.

The first chapter encompasses seven papers addressing the fundamental mechanisms that lead to superplastic behaviour. The five papers included in the second chapter can be classified into two groups by their topical coverage: modelling of superplastic forming, and cavitation studies. The modelling studies presented in the first two papers are aimed at predicting optimum rates of pressurization which will result in minimum cavitation and maximum formability. The papers on cavitation address the fundamental mechanisms controlling void formation and linkage during superplastic deformation. Since it is widely recognized that most superplastic alloys cavitate during deformation, it is important to design alloys and utilize processing methodologies that minimize cavitation. According to the discussion presented in these three papers, one can minimize cavitation, for example, by superimposing a large hydrostatic stress during deformation, minimizing the presence of pre-existing defects, altering the grain size, and/or changing deformation parameters such as strain rate of temperature.

The third chapter encompasses four papers addressing the important subject of superplasticity in Al-Li alloys. Al-Li alloys have demonstrated the potential for providing a class of high strength alloys with exceptional properties suitable for weight-critical and stiffness-critical applications. Superplastic forming of these materials is actively being studied as a means of offsetting the higher costs associated with the lithium additions. The results discussed in this section suggest that with suitable thermo-mechanical treatments it is possible to develop microstructures that will exhibit superplasticity. It was confirmed that a number of materials, including: Al-Li-Cu-Mg-Zr (8090, 8091), 2090, and 2024/SiC (whiskers and particulates), will exhibit superplasticity when subjected to appropriate thermo-mechanical treatments.

The fourth chapter presents a perspective on the advances and challenges faced by industry and addresses critical issues associated with the production of commercial aerospace parts using superplastic forming.

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Materials, principles, and practice

Edited by C. Newey & G. Weaver. Butterworth Scientific Ltd., Guildford. 1990. 405 pp. Price £18.95. ISBN 0-408-02730-4

The book is divided into seven chapters. In chapter 1 much emphasis is made of the relationship between materials as products, the properties of materials, the processing of materials, and scientific principles.

In chapter 2, under the title "The nature of materials", scale (size) and mixture, macrostructure, toughness, microstructure, and soft and hard magnetic materials are all addressed.

Chapters 3 and 4 are devoted to bonding in solids, and temperature as an element of change.

The subject of chapter 5 is mixtures and phase transformations.

Chapter 6 is concerned with how the mechanical properties of materials influence processing. The importance of elasticity, ductility, and brittle behaviour in processing is considered, and it is shown how these properties can be related to the microstructure of a material.

In chapter 7 the chemistry of material processing is considered, the oxidation-reduction of materials taking up a large proportion of the chapter.

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A Fractography Atlas of Casting Alloys is a new reference for engineers and failure analysts who must examine fracture surfaces to determine the cause of failures. The atlas provides optical and SEM photomicrographs at various magnifications of representative, commonly used alloys that have been broken under documented loading conditions. The authors have systematically documented the fractography of 10 commonly used alloys: as-cast grey iron; heat-treated grey cast iron; pearlitic ductile iron; ferritic ductile iron; austempered ductile iron; heat-treated cast steel; aluminium-base alloys A380, A356 and A319; and cast and HIP Ti-6Al-4V. 196 pp. $87.50 plus $3.50 shipping. *Contact: Battelle Press, 505 King Ave., Columbus, Ohio 43201-2693; 800/451-3543; Fax: 614/424-5263; electronic mail SHELDRIC&BATELLE.ORG.*

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Structure and Properties of Interfaces in Materials from the Materials Research Society (MRS) focuses on issues arising from the relationships between the structure, chemistry and properties of interfaces in metals, ceramics, semiconductors and composites. The 889-page volume includes papers on composites and high-temperature materials. $47 (MRS members), $54 (US list) and $70 (foreign). *Contact: MRS, Publications Dept., 9800 McKnight Road, Pittsburgh, Pennsylvania 15237; 412/367-3012; Fax: 412/367-4373.*

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Manufacturing with materials

Edited by L. Edwards & M. Endean, Butterworth Scientific Ltd., Guildford. 1990. 432 pp. Price £22.50. ISBN 0-408-02770-3

The book focuses on how materials are processed into different shapes, and examines how choosing a particular process for making a product involves considering both the shape of the product and the materials it is to be made from. Unusually, an attempt is also made to show the importance of non-technical aspects of manufacturing, such as marketing, on how products are made. All aspects of manufacture and the complex interrelationships between process, properties, and design are considered with a little discussion of microstructures included. The manufacturing processes are grouped according to the basic principles by which they operate - casting, forming, cutting (machining), and joining.

Chapter 1, *"Materials and manufacturing"*, considers manufacturing as a system and steps in the process are shown on flow charts with, for example, raw materials as input and products and waste as output. This simple but useful concept is used and developed throughout the book. Also covered briefly in this chapter are the types of material, design concepts, surface engineering, and the product and market place. Chapter 2, *"Casting"*, considers all types of casting such as continuous, investment, die, and squeeze and moulding processes such as injection, compression, rotational, etc.: nucleation, growth, heat transfer, and mould filling concepts are covered in detail. *"Forming"*, chapter 3, emphasizes the effect of the various forming processes (e.g. forging, rolling, extrusion, blow moulding, and slip casting) on microstructure and the resulting properties. Chapter 4, "*Cutting*", describes single point and multiple point cutting mechanisms, grinding, and electrical discharge and electrochemical machining. In all cases both cutting materials and materials to be cut are reviewed.

Welding, brazing and soldering, adhesive bonding (glues), and fasteners (rivets and bolts) comprise chapter 5, "*Joining*", while chapter 6 "*Manufacturing decisions*", is a useful diversion into marketing and business strategy. Chapter 7, "*Controlling product quality*", examines methods of quality control and assurance including acceptance sampling and statistical process control. Chapter 8, "*The electric kettle*", is a case study illustrating how decisions involving product design, manufacturing process, and materials lead to a diversity of products and manufacturing solutions.

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Directory of Advanced Material Professionals

This directory, published four times a year, lists the names and titles of engineers, scientists, professors, research professionals, marketing professionals, and consultants. It features more than 14,000 listings, cross-referenced by company, profession, region, and alphabetical. One year subscription is $399; single issue is $150. *Order from CEMS Publications, 8807 Mohawk Way, Fair Oaks, CA 95628, USA.*

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American Society for Composites, Sixth Technical Conference: Composite Materials, Mechanics and Processing

These proceedings of a conference held in 1991 contain more than 100 reports on the materials, mechanics, and processing aspects of composite materials, as well as metal and ceramic matrix composite systems. Topics include structure-property relationships, laminates and analysis, ultimate properties, interfaces, design, structures and non-destructive evaluation, processing, and micromechanics. Many photographs, microphotographs, and schematics accompany the text. *Hardcover, 1991, 1100 pp. $175, ISBN 0-87762-893-9. Order from Technomic Publishing Co., Inc., 851 New Holland Ave., Box 3535, Lancaster, PA 17604, USA.*

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A look into the advanced materials industry

The *Advanced Materials Sourcebook and Directory 1991-1992* is now available from Elsevier as a softcover two-volume set for US$450. The sourcebook (Volume 1) provides general information on the advanced materials industry, concentrating on ceramics, composites, plastics, and the companies that produce these materials. The directory contains a detailed address list of the companies mentioned in the sourcebook.

For more information contact *Elsevier Advanced Technology Orders Department, Mayfield House, 256 Banbury Road, Oxford, OX2 7DH, UK. Fax: (+44)(0) 865 310981.*

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International Encyclopedia of Composites, *Vol. 1-4. VCH Publishers. New York 1990: DM 450.00 each, subscription price DM 370.00 each (Vol. 1-6); ISSN 0935-9648.* The publication of this reference work is a noteworthy event in the field of modern materials science in view of the great importance of these materials in advanced technology.

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A new science dictionary

A new scientific dictionary is now available from Academic Press. With approximately 115,000 fully defined entries in 2,200 pages, the *Academic Press Dictionary of Science and Technology* claims to have the largest collection of scientific terms of any dictionary of its kind.

Further information obtainable from: *Academic Press, Harcourt Brace, Jovanovich Publishers, Book Marketing Department, 24-28 Oval Road, London NW1 1YA, UK.*

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Who's Who in Technology

Two volumes. Edited by Amy L. Unterburger. 6th edition. Detroit: Gale, 1989. 2742 pp. $380. 509.2 TA 139 ISSN 0877-5901 ISBN 0-8103-4950-7.

Contents, Vol. Biographies: Key to biographical information. Abbreviations table. Biographies. Obituaries.

Contents, Vol. Indexes: How to use the *Who's Who in Technology* indexes. Geographic index. Employer index. Technical discipline index. Electronics and computer science. Mechanical engineering and materials science. Chemistry and plastics. Civil engineering, earth sciences and energy. Physics and optics. Biotechnology. Expertise index.

Note: Includes approximately 38,000 North American men and women who have made outstanding contributions to the advancement of science, engineering and/or technology as evidenced by patent output, publications, awards, special achievements and positions of responsibility. Entries are arranged alphabetically in one volume; a separate index volume enables the user to identify individuals by geographic location, employer, technical discipline and expertise. An obituaries section, new to this edition, lists biographees known to have died since the previous edition. A full entry and death date, if available, are provided. For science and technology research level reference collections.

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7. PAST EVENTS AND FUTURE MEETINGS

1992

During the summer of 1992 (28 August - 5 September) as many as 5,000 of the world's leading space scientists and engineers came to Washington D.C., USA, to participate in the first **WORLD SPACE CONGRESS**. It was hosted and sponsored by the American Institute of Aeronautics and Astronautics (AIAA) and the National Academy of Sciences and NASA.

12-16 October Moscow — International Conference on Technology Assessment in Conversion for Development, Industry Focus I: Aerospace Technology (Org. by Science, Technology, Energy, Environment and Natural Resources Division of the Department for Economic and Social Development of the United Nations, in cooperation with the Government of the Russian Federation and in collaboration with UNDP, Office for Outer Space Affairs, United Nations Department of Political Affairs and UNIDO).

23-25 October Sydney, Australia — Australian Space Development Conference 1992 (National Space Society; further details can be obtained from Kirby Ikin, GIO Reinsurance, GPO Box 1559, Sydney NSW 2001, Fax: (02) 235-3909)

15-18 November Zhukovsky, Russian Federation — Seminar on Russian Military/ Industrial Conversion with Aerospace Research and Development Focus. The OECD Centre for Co-operation with the European Economies held a three-day seminar discussing policy issues, including potential business development, concerning the conversion of military research in the aviation sector. The seminar was held at the Russian aerospace research and testing facilities in Zhukovsky, near Moscow.

Participants included Russian aerospace industry officials and experts, industrialists and officials from the aerospace sector of OECD Member countries, representatives from the international banking community and OECD secretariat specialists.

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1992

30 September - 1 October Brussels, Belgium — Strategies for Plastics Recycling (European Centre for Plastics in the Environment, 43-45 St. John Street, London EC1M 4AN, UK, Fax: +44 (0)71 490 3319)

7-9 October Piestany, Slovakia — 8th International Conference on Powder Metallurgy (Director Ing. Jiri Miculek, Vyzkumny ustav pro praskovou metalurgii, Zerotinova 60, CS-78763 Sumperk, Fax: (00 42-649) 53.93)

2-5 November Chicago, Illinois, USA — Technology Transfer and Commercialization. 8th Annual ASM/ESD Advanced Composites Conference & Expo (ASM International, Materials Park, Ohio 44073-0002 and ESD [Engineering Society])

16-17 November Miami, Florida, USA — Symposium on Application of Accelerated Corrosion Tests to Service Life Prediction of Materials (ASTM, 1916 Race Street, Philadelphia, PA 19103-1187, USA, Fax: 0462-433678)

8-9 December London, UK — Corrosion and Related Aspects of Materials for Potable Water Supplies (The Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB, UK Fax: +44 (0)71 839 3576)

1993

1-4 February Albuquerque, NM, USA — Conference on Smart Structures and Materials (SPIE, Box 10, Bellingham, WA 98227-0010, USA, Fax: 206/647-1445)

2-4 March Singapore
UTECH Asia '93 - Growth through Technology, Conference and Exhibition for the Polyurethanes Industry in the Asia-Pacific region. (Crain Communications Ltd., Cowcross Court (2nd Floor), 75-77 Cowcross Street, London EC1M 6BP, Fax: +44 (0)71 608 1173)

17-18 March London
Plastics Recycling Pursuing the Challenge (Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB)

23-26 March Dresden, Germany
International Conference on Materials by Powder Technology (Deutsche Gesellschaft für Materialkunde e. V., Adenauer-allee 21, Oberursel, Germany, Fax: 06171/52554)

7 April Birmingham, UK
Design against Corrosion (Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB, Fax: +44 (0)71 839 3576)

19-20 April Geneva
The Business of Plastics; A Modern Plastics Technology Briefing, 1 Battelle Europe (Freehold Exec. Center, Seminars, 4400 Route 9 South, Suite 1000, Freehold, NJ 07728, USA)

21-23 April Paris
JEC '93 - European Composites Congress (CPC 65, rue de Prony, 75017 Paris)

21-25 May Hong Kong
Plastics Asia '93 (Business and Industrial Trade Fairs Ltd., 18/F, First Pacific Bank Centre, 51-57 Gloucester Road, Wanchoi, Hong Kong

1-4 June Friedrichshafen, Germany
German Materials Society, Annual Meeting (DGM, Adenauerallee 21, W 6370 Oberursel, FRG, Fax: 06171-52554)

6-12 June Potsdam, NY, USA
Materials Processing in High Gravity (International Center for Gravity Material Science and Applications, Potsdam, NY 13699, USA)

6-19 June Sophia Antipolis, France
Nanochemistry. Advanced Study Institute Sophia Antipolis (France). Contact: Prof. H. Siegenthaler, Universität Bern, Inst. für Anorganische Chemie, Freiestrasse 3, CH-3012 Bern, Switzerland

7-10 June Paris, France
Euromat '93, 3rd European Conference. Contact: EUROMAT '93, Société Francaise de Metallurgie et de Matériaux, 1, rue Paul Cézanne, F-75008 Paris, France

7-10 June Yokohama, Japan
Solid-State Sensors and Actuators (Transducers-7) Conference. Contact: SANSEI International Inc., Fukide Bldg. No. 2, 1-21 Toranomon 4-chome, Minatoku, Tokyo 105, Japan, Fax: (81)-3-3433-1612

7-11 June Oahu, HI (USA)
Nondestructive Characterization of Materials, 6th International Symposium. Contact: D. Harris, Johns Hopkins University, 102 Maryland Hall, Baltimore, MD 21218, USA, Fax: 410 516 5239

7-13 June Aghia Pelaghia, Crete, Greece
Physics and Chemistry of the Fullerenes. Advanced Research Workshop. Contact: Dr. K. Prassides, University of Sussex, School of Chemistry and Molecular Sciences, Falmer, Brighton, BN1 9QJ, England

14-18 June Jülich, Germany
Semiconductor Interfaces. 4th International Conference. Contact: Forschungszentrum Jülich GmbH, attention: B. Lengeler, Postfach 19 13, W-5170 Jülich, FRG

14-25 June Marathon, Greece
Nanophase Materials: Synthesis, Properties, Applications. Advanced Study Institute, Marathon, Greece. Contact: Prof. G. C. Hadjipanayis, University of Delaware, Physics & Astronomy Department, Newark, DE 19716, USA

22-25 June
Singapore

Advanced Materials (M'93). International Exhibition and Conference. Contact: Times Conference and Exhibition Pte. Ltd., Times Centre, 1 New Industrial Road, Singapore 1953, Singapore

24-25 June
Atlanta, GA, USA

Acousto-Ultrasonic Materials Characterization. 2nd International Conference. Contact: American Society for Non-destructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Colombus, OH 43228, USA

1-12 July
Erice, Italy

Nonlinear Optical Materials and Devices for Applications in Information Technology. Advanced Study Institute, Erice, Italy. Contact: Prof. A. Miller, University of Central Florida, Electrooptics & Laser Center, 12424 Research Pkwy, S.400, Orlando, FL 32826, USA.

2-6 July
Shanghai

International Mechatronic Technology and Equipment Exhibition (organized by Paper Comm. Exh. Serv., Room 16, 12/f, Wah Shing Centre, 11 Shing Yip Str., Kwuntong, Kowloon, Hong Kong)

4-9 July
Quebec, Canada

Organized Molecular Films. 6th International Conference. Contact: Dr. Pierre-F. Blanchet, Chairman, Dept. de Chimie-Biologie, Univ. du Québec à Trois-Rivières, Canada, Fax: (1) 819 376 5057, Tel.: (1) 819 376 5052

4-9 July
Jerusalem, Israel

The Chemistry of the Organic Solid State (ICCOSS-XI), 11th International Conference, Kibbutz Ramat Rachel, Jerusalem, Israel. Contact: Dr. G. Berkovic, Dept. of Materials and Interfaces, Weizmann Institute of Science, Rehovot, Israel 76100, Fax: 972-8-3441338

12-15 July
Prague, CSFR

Polymers. 33rd Microsymposium. Contact: PMM Secretariat; attention: Institute of Macromolecular Chemistry, Czechoslovak Academy of Sciences, 16206 Prague, CSFR, Fax: 42 (2) 367981

12-16 July
Madrid, Spain

Composite Materials. 9th International Conference. Contact: A. Miravete, Department of Mechanical Engineering, University of Zaragoza, Maria de Luna 3, 50015 Zaragoza, Spain, Fax: (34)-76-612932

12-16 July
Albuquerque, NM, USA

Cryogenic Materials Conference. Contact: Los Alamos National Laboratory, Protocol Office, attention: J. Hull, P.O. Box 1663, MS P366, Los Alamos, NM 87545, USA

16-21 July
Boca Raton, FL, USA

Metallic Alloys: Experimental and Theoretical Perspectives. Advanced Research Workshop. Contact: Prof. J. S. Faulkner, Florida Atlantic University, Physics Dept., Boca Raton, FL 33431, USA

18-30 July
Antalya, Turkey

Supercritical Fluids - Fundamentals for Application. Advanced Study Institute, Antalya, Turkey. Contact: Prof. E. Kiran, University of Maine, Dept. of Chemical Engineering, Orono, ME 04469, USA

19-22 July
Prague, CSFR

Fluorinated Monomers and Polymers. 34th Microsymposium. Contact: PMM Secretariat, 34th Microsymposium; attention: Institute of Macromolecular Chemistry, Czechoslovak Academy of Sciences, 16206 Prague, CSFR

19-22 July
Aberdeen, Scotland, UK

Materials Chemistry. 1st International Conference. Contact: Dr. John F. Gibson, The Royal Society of Chemistry, Piccadilly, Burlington House, London W1V 0BN, UK

20-22 July
Cambridge, UK

Polymers, International Conference. Contact: The Polymer Conference Meetings Management, attention: J. Herriot, Straight Mile House, Tilford Road, Rushmoor, Farnham, Surrey, GU10 2EP, UK

23-25 July
Santa Barbara, CA, USA

Electronic Materials Conference. Contact: Minerals, Metals and Materials Society, Meeting Services Department, 420 Commonwealth Dr., Warrendale, PA 15086, USA

28 July - 1 August
Makuhari Chiba, Japan

Silicon Molecular Beam Epitaxy (MBE) 5th International Symposium. Contact: University of Tokyo, Research Center for Advanced Science and Technology, attention: Prof. Y. Shiraki, 4-6-1 Komba, Meguro-ku, Tokyo 152, Japan

31 August - 4 September
Sunshine City Ikebukuro, Tokyo, Japan

Third MRS International Conference on Advanced Materials. Many symposia are planned: composites, glassy materials, powder preparation, computer applications in materials, science and engineering, superplastic phenomena, materials interconnection, corrosion/coating, shape memory materials, hydrogen absorbing materials, structural ceramics, biomaterials, and so on. (3rd MRS International Conference on Advanced Materials, c/o Nikkan Kogyo Shimbun, Ltd., Business Bureau, 8-10 Kudan-Kita, 1 Chome, Chiyoda-ku, Tokyo 102, Japan, Fax: +81-3-3221-7137)

6-8 October
Gaithersburg, MD, USA

4th International Symposium on Computerization and Use of Materials Property Data (ASTM, 1916 Race Street, Philadelphia, PA 19103-1187, USA, Fax: 215/977-9679)

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