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"RESEARCH PROGRAM FOR RADIATION STABILITY OF THE AEROSPACE MATERIALS – TRANSFER OF THE KARPOV INSTITUTE DATABASE ON RADIATION STABILITY OF ORGANIC MATERIALS"

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This report results from a contract taskingKarpov Institute of Physical Chemistry as follows: The contractor will investigate the long-term stability of materials subjected to the space radiation environment. This will involve detailed analysis of previously acquired data and comparison with similar data from other sources. All data will be conveniently packaged for future work using off the shelf database tools.

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In 1999, a contract was concluded between EOARD and Karpov Institute to create a Database on the radiation stability of organic materials. The Database has incorporated the results of tests conducted at Karpov Institute. Such tests have been carried out at the Institute for the last 30 years on orders from enterprises of the Soviet space and defense industries, such as the Khrunichev State Space Science and Industry Center, the Korolyov Rocket-Space Corporation "Energia", the Lavochkin Science and Industry Association, the Krasnoyarsk Science and Industry Association of Applied Mechanics, the "Composite" Science and Industry Association, etc.

Work on the Database consisted of the following stages:

1. **Selection of test results on the radiation stability of organic materials published in reference books, scientific papers, proceedings of conferences, as well as data contained in reports and records of tests conducted on orders from industrial enterprises.**
2. **Analysis of the chemical structure, types and functions of the materials, classification of the test results according to groups of properties, types and conditions of the action of ionizing radiation.**
3. **Developing the structure of the Database using Microsoft Access 97.**
4. **Input of the data, optimizing the structure of the Database and the system of its management. Translating the Database into English.**

Test results for 638 materials were selected for inclusion into the Database. Appendix1 contains a list of the information sources that were used for selecting the test results.

Based on an analysis of their chemical structure, types and functions, the materials have been divided into 14 types:

Material types	
1. Adhesives	8. Inorganic materials
2. Coatings	9. Paints, lacquers, enamels
3. Composites	10.Plastics
4. Compounds, compositions	11.Products
5. Films	12.Resins
6. Foamed materials	13.Rubbers
7. Hermetics	14.Textile materials

MATERIAL TYPES

I. ADHESIVES

Phenol-formaldehyde	Epoxy	Organosilicone	Others

Adhesives are compositions capable of forming stable adhesive links with different

surfaces.
In space vehicles, adhesives are used for gluing construction parts together.
The Database includes test results for 41 brands of adhesives based on phenol-formaldehyde, epoxy, organosilocone and other resins.
Table 1 presents the functions in space vehicles of some brands of adhesives included into the Database. The names of the adhesives used in theMir space station are given in red.

Table 1

Material	Function of the material on the external surface of the space vehicle
1. Adhesive K-400	Gluing the T-13 fabric to VT-14 on the Mir station
2. Adhesive VK-36	Gluing the SSP-1 honeycomb glass plastic in a three-layer construction on the Mir station
3. Adhesive 88NP	Gluing foil to the docking plane of the load box on the Mir station
4. Adhesive Balzamin-M	Optical adhesive for gluing together components of optical devices
5. Adhesive BF-4	Adhesive dip of the net fiber of the space vehicle cable system (SVCS), fixing beltlines on the Mir station
6. Adhesive VK-9 (cold curing)	Locking screw joints, gluing textile fastening and brackets to equipment body, fixing detectors on the Mir station
7. Adhesive K-153	Gluing together components of optical devices, gluing braces and brackets to containers, locking screw joints on the Mir station
8. Adhesive K-300-61 (cold curing)	Locking screw joints, gluing components of the guardrails of PO-2 on the Mir station
9. Adhesive Cryosil	Gluing parts of the system of cryogenic heat insulation for temperatures 20-473 K
10. Adhesive OK-72-FT_5 (optical)	Gluing together components of optical devices
11. Adhesive UP-4-260-3M (optical)	Gluing together components of optical devices
12. Adhesive ED 6-8	Gluing together components of optical devices
13. Adhesive EKAN-3	Gluing together components of optical devices
14. Adhesive EPK-1	Locking screw joints, gluing textile fastening to equipment body on the Mir station
15. Adhesive 88SA	Gluing rubbers, polyurethane, technical fabrics

16.Adhesive K-153 NB	Locking screw joints on the Mir station
17.Adhesive K-153 NK	Locking screw joints on the Mir station
18.Adhesive K-153 NK (black)	Locking screw joints on the Mir station

II. PAINTS, LACQUERS, ENAMELS

Epoxy	**Polyacrylate**	**Amino-formaldehyde**
Organosilicone	**Phenol-for-maldehyde**	**Polyether**

Lacquers, paints and enamels are solutions or suspensions film-forming substances (polymers, oligomers, monomers).

They serve protective, decorative and thermal control purposes on the external surfaces of space vehicles.

The Database includes test results for 91 brands of lacquers, paints and enamels based on epoxy, phenol-formaldehyde and aminoformaldehyde resins, as well as polyacrylate, polyether and polyorganosiloxane.

Table 2 presents the functions in space vehicles of some brands of lacquers, paints and enamels included into the Database.

Table 2

Material	Function of the material on the external surface of the space vehicle
1. Paint TNPF-851	Studied as coating for components of optical devices
2. Lacquer AK-113F	Used in manufacturing components of optical devices
3. Enamel AK-243 (black)	Coating for blinds in optical devices
4. Enamel AK-512 (white)	Thermal control coating (TCC)
5. Enamel AK-512 (black)	TCC
6. Enamel AK- 573	TCC in early space vehicles, the first underlayer in the Moon Robot
7. Enamel KO-5191 (white)	TCC
8. Enamel KCh-5269	Studied as coating for components of optical devices in space vehicles

9. Enamel KhS-543 (black)	Studied as coating for components of optical devices in space vehicles
10. Enamel KhS-928 (electroconductive, black)	Coating for protecting metallization spots
11. Enamel EP-140	Coating for construction materials on the Mir station
12. Enamel EP-140 (white)	Coating for construction materials on the Mir station
13. Enamel EP-140 (black)	Coating for construction materials on the Mir station
14. Enamel EP-730	Coating for construction materials on the Mir station

III. COMPOUNDS, COMPOSITIONS

Epoxy | **Phenol-formaldehyde** | **Organosilicone** | **Others**

These group of materials includes compositions based on polymers, oligomers and monomers intended for potting and impregnating current-conducting circuits and other elements of electronic equipment.

In space vehicles, materials of this group are used on the external surfaces for protection against environment effects and mechanical impacts.

The Database includes test results for 51 brands of compounds and compositions based on lacquers, paints and enamels based on epoxy, phenol-formaldehyde and organosilicone resins.

Table 3 presents the functions in space vehicles of some brands of compounds and compositions included into the Database.

Table 3

Material	Function of the material on the external surface of the space vehicle
1. Compound EZK-6 (potting)	Fixing wires in plug cutouts on the Mir station
2. Compound KCz	Studied as a material for manufacturing parts of optical devices in space vehicles
3. Compound EDL-20 MB	Fixing wires in plug cutouts on the Mir station
4. Compound 10-80-2M	Used for manufacturing parts of optical devices in space vehicles
5. Compound Vixynth K-68	Fixing wires in plug cutouts on the Mir station
6. Compound Vixynth PK-68	Potting elements of electronic equipment

7. Compound K-115 NK	Used for manufacturing parts of optical devices in space vehicles
8. Compound K-153 (potting)	Used for manufacturing parts of optical devices in space vehicles
9. Compound UP-5-220	Potting elements of electronic equipment

IV. HERMETICS

Polyurethane **Organosilicone** **Phenol-formaldehyde**

Polyacrylate **Epoxy**

Hermetics are compositions based on polymers and oligomers intended for applying to bolted, riveted and other joints to achieve their impermeability.
The Database includes 28 brands of polyurethane, polyacrylate, organosilicone, epoxy and phenol-formaldehyde hermetics.
The purposes served by some of them on the external surface of the space vehicle are presented in Table 4.

Table 4

Material	Function of the material on the external surface of the space vehicle
1. Hermetic VER-1	Potting of riveted, welded, bolted, flange and others metal joints
2. Hermetic Anaterm-4	Fixing screw joints on the Mir station
3. Hermetic Vixynth U-1-18	Potting of the electrical insulation of contacts and connectors of Mir station equipment
4. Hermetic VGO-1 with underlayer P-11	Potting of the electrical insulation of electronic and radio equipment and movable contacts of connectors
5. Hermetic Vixynth U-2-28	External and internal hermetic sealing of construction elements on the Mir station
6. Hermetic VGO-1	Potting of the electrical insulation of electronic equipment and movable contacts
7. Hermetic 51-G-23	Fixing and hermetically sealing electronic equipment
8. Hermetic UT-34	Filling up junction corner slots in optical devices in space vehicles

V. COMPOSITES

Epoxy	Phenol-formaldehyde	Urea-formaldehyde-aminoplast
Based on filled polymers	**Organosilicone**	**Other**

Composites are multicomponent heterogeneous materials. They consist of a filler (a natural or synthetic organic and/or inorganic fiber) and a binder (as a rule, an organic resin).
The Database includes test results for 87 composites.
Table 5 presents several brands of composites.

Table 5

Material	Function of the material in the space vehicle
1. Glass plastic STP	A construction material, thermal shields for the STR panel, thermal bridges, fixing of guardrails. Used for the installation of NHR panels.
2. Composite heat-shielding AFT-2 (AFT-2P)	Thermal bridges, gaskets, fixing of guardrails, used as a protective construction material on the Mir stations
3. Composite heat-insulated and sound-proof ATM-1	Thermal insulation of the walls of the dry modules on the Mir station
4. Composite heat-insulated and sound-proof ATM-3	Thermal insulation of the SOTR pipelines on the Mir station
5. Carbon plastic KMU	A construction material. Profiles for the installation of the NHO panels on PO-2 on the Mir station
6. Composite Getinaks	An unstrained construction material. Clouts and gaskets on the Mir station
7. Moulding material AG-4V	Parts of space vehicle optical devices working outside the pressurized compartments
8. Moulding material AG-4S	Parts of space vehicle optical devices working outside the pressurized compartments

9. Glass textolite DSV-2R-2M	An unstrained construction material. Used for manufacturing covers, brackets and cradles on the Mir station
10.Glass textolite VFT-S	An unstrained construction material
11.Composite KAST-V (glass textolite)	A construction material, heat insulation gaskets under the covers of portholes on the Mir station
12.Glass textolite STEF	A construction material
13.Carbon plastic KMU-9	A construction material

VI. TEXTILE MATERIALS

Arimide | **Capron** | **Phenylone**

Polyethyleneterephtalate | **Alumina borosilicate** | **Other**

The group of textile materials includes fabrics, tapes, fibers, threads and cords. From the point of view of the chemical structure, the Database includes mainly arimide, capron, phenylone, polyethyneleterephtalate and alumina borosilicate textile materials.
The Database includes data on 63 brands of textile materials.
Table 6 presents several of them that are used in space vehicles.

Table 6

Material	Function of the material in the space vehicle
1. Capron cord ShKP-90	Halyards of the Mir station
2. Fabric KT-11	Used for fixing brackets of the SVCS and cradles on the Mir station
3. Fabric NT-7 gummed vulcanized	Used for facing the SVCS. Protection against effects of the environment
4. Glass fabric type TSON-IP"S" (optical function)	For facing the mats of thermal blankets on the Mir station

5. Glass fabric type TSON-SOT (optical function)	For facing the mats of thermal blankets in space vehicles
6. Glass fabric type TSON-SOTMbc (optical function, metallized)	For facing the mats of thermal blankets on the Mir station
7. Glass tape T-13	Faceplate on the Mir station
8. Tape grade KL-11-5,0	For attaching detectors to brackets
9. Tape grade KL-11-5,0-SF	For attaching detectors to brackets
10. Net fiber SS1RU-4-9x9	For fixing elements of electronic equipment on the BS
11. Arimide duck frame fabric article 56420	Fabric used on the external surfaces of the space vehicle
12. Arimide fabric article 5355/3-85 (black, carbon filled)	Fabric used on the external surfaces of the space vehicle
13. Arimide fabric article 5380- 77	Fabric used on the external surfaces of the space vehicle
14. Arimide fabric article 5388-84	Fabric used on the external surfaces of the space vehicle
15. Arimide fabric article 5401/2-78	Fabric used on the external surfaces of the space vehicle

VII. PRODUCTS

The Database includes test data on 15 ready-made products used in space vehicles.

Table 7

Material	Function of the material in the space vehicle
1. Tape LETSAR-BP-0.2	Insulation of cables
2. Adhesive tape LT-19	For shaping cables on the Mir station
3. Adhesive tape A30	For protection of labels on the Mir station
4. MPMOS wire with polyethylene insulation	Used in electric wiring in the optical devices of space vehicle
5. Tube F-4D	For protecting wires in plug cutouts of the SVCS on the Mir station
6. Polyvinylchloride tape	For shaping cables on the Mir station

7. Glass tape LES (electric insulating)	For shaping cables, fixing brackets, manufacturing beltlines, fixing the mats of the thermal blankets on the Mir station
8. Textile fastening	For holding mats of the thermal blankets on the Mir station

VIII. RUBBER

Natural	**Butadienenitrile**	**Fluoro-elastomer**
Silicone	**Olefine copolymers**	**Styrene-olefine copolymers**

The Database presents test results for 44 rubbers. The studied rubbers belong to the following groups: natural, silicone, butadienenitrile, olefine copolymer, fluoroelastomer, styrene-olefine copolymer. Rubbers are used on external surfaces for holding and facing the detectors and cables of the space vehicle cable system.

The Database includes test results for 5 **inorganic materials (glasses)** used in the optical devices of space vehicles.

Also included are results of tests for 11 **coatings.** They are mainly epoxy and polyalkylsiloxane coatings.

IX. COATING

Epoxy	**Polyalkylsiloxane**	**Other**

The coatings included in the present Database serve the purposes of protection, electrical insulation and thermal control.

The Database contains test results for 14 **foam plastics.** In space vehicles, these materials are used as heat insulation materials and construction fillers.

Pure (non-composite) substances were included into two material type groups: **films** and **plastics**. The results of tests for these materials allow to predict their behavior in constructions and products. The Database includes 73 brands of films and 106 brands of plastics.

RADIATION TYPE

The Database presents the results of tests of the radiation stability of the materials under the action of gamma, electron, proton, pile and electromagnetic radiation.

Table 8

Gamma	^{60}Co sources with the quantum energy 1.25 MeV were used for gamma-irradiation. Most data were obtained in the dose rate range 0.01 – 800 Gy/s. The irradiation environments were air and vacuum. The absorbed dose, as a rule, was no more than 3 MGy.
Electrons	The linear electron accelerator ELU-2-8 was used for electron irradiation. The electron energy equaled 9MeV. Dose rate, 10 – 1000 Gy/s. Irradiation environment: air, vacuum. Part of the data was obtained on linear electron accelerators with the electron energy 20-400 keV. Irradiation environment: vacuum. Dose rate 10 – 500 Gy/s. Absorbed doses up to 500 MGy.
Protons	The results were obtained under irradiation with protons with the energy 20 – 200 keV. Irradiation environment, vacuum. Fluence up to 10^{19} cm^{-2}.
Electromagnetic radiation	The samples were irradiated in a range of wavelengths simulating the extraterrestrial radiation of the Sun (0.2 – 2.5 mcm). DKsShRB - 3000 - 5000 xenon superhigh pressure arc-lamps were used for this purpose. Part of the data was obtained using PRK-2 mercury lamps. Irradiation environment: vacuum. Exposition time up to 1500 equivalent solar days. Intensity from 1 to 10 Suns in ultraviolet.
Pile radiation	The samples were irradiated on the Karpov Institute WWR-c reactor, in its experimental vertical and horizontal channels and thermal column niche. Types of radiation: mixed gamma-neutron radiation and filtered gamma-radiation. Specific neutrons flux, 10^{12} cm^{-2}. Irradiation environment, air vacuum. Absorbed doses up to 10 MGy.

PROPERTY GROUPS

The Database includes the test results on the mechanical, conductive, dielectric, thermophysical and optical properties of the materials after ionizing and electromagnetic irradiation, as well as data on the mass loss and gas evolution of the irradiated samples. The data are presented both in graphic and table format.

I. MECHANICAL PROPERTIES

Data on the following mechanical parameters are given:

1. **tensile strength** σ

2. **ultimate deformability ε**
3. **tensile stress F/d**
4. **bending strength σ_b**
5. **compression strength σ_c**
6. **impact strength a_k**
7. **shear strength τ**
8. **modulus of elasticity E**
9. **exfoliation strength**
10. **tearing strength**
11. **Shor hardness**
12. **Parameters of the creep.**

The creep rate is determined by the velocity of the relative deformationε: $V_{cr} = d\varepsilon/dt$. The dose rate, stress and temperature dependences of the creep rate have been studied. The parameters of the creep are connected with each other by the following empirical dependence:

$$V_{cr} = AR^{\Delta}\exp(\alpha\sigma + \beta T)$$

Here

A is the constant of the creep rate characterizing its dependence on the dose rate, $0.5 < \Delta < 1$ – exponent,

α is the constant of the creep rate characterizing its dependence on the stress σ,

β is the constant of the creep rate characterizing its dependence on the temperature T.

13. **Parameters of the longevity τ: $\tau = B/V_{cr}$ (B is the constant).**

Longevity is determined by the time of the rupture of the sample with the stress kept constant. The dose rate, temperature and stress dependences of the longevity have been studied.

The Database contains 648 records on the mechanical properties of the irradiated materials.

II. OPTICAL PROPERTIES

The following optical parameters of the irradiated materials are presented in the Database:

1. α_S and α_λ - integral and spectral absorption coefficient of solar radiation (0.2 – 2.5 mcm);

$\Delta\alpha_S = \alpha_S$(irrad) - α_S(unirrad) – change of absorption coefficient of solar radiation

2. τ_S and τ_λ - integral and spectral transmission coefficient of solar radiation;

ρ_S and ρ_λ - integral and spectral reflectance coefficient of solar radiation;

3. ε_H – integral coefficient of heat emission to a hemisphere;

4. D and D/x - optical density and relative optical density reduced to the unit of the sample thickness;

5. Absorption spectra;

6. Change of materials color and appearance;

6. The groups of relative radiation and light stability;

The Database contains 242 records on the optical properties of the irradiated materials.

III. DIELECTRIC PROPERTIES

The following dielectric parameters of the irradiated materials are given in the Database:

1. ε - dielectrical permittivity
2. tanδ - tangent of dielectric loss angle
3. E_{ST} – electric strength

The Database includes the temperature and frequency dependences of these parameters for different absorbed doses and irradiation conditions (with varying the environment, temperature and dose rate).
Besides, data are presented on the change of these parameters directly during the action of ionizing radiation on the samples for different frequencies, including superhigh frequencies.

The Database contains 254 records on the dielectric properties of the irradiated materials.

IV. CONDUCTIVE PROPERTIES

The Database presents:
1. The specific volume and surface conductivity of the original and irradiated samples. The effect on them of the absorbed dose and the irradiation conditions (environment, temperature, dose rate, mechanical pressure).
2. Radiation-induced volume and surface conductivity, $\sigma_p = A(R/R_0)^{\Delta}$ and $\sigma_p = A_S(R/R_0)^{\Delta}$ respectively (A and A_S are constants characterizing the electrical conductivity for the dose rate equal to one). The effect on them of the dose rate, field intensity and temperature. Data are given on the influence of the physical structure of the materials on their conductive properties (crystallinity, orientation of the polymer chains, annealing and quenching of the samples).

The Database contains 514 records on the conductive properties of the irradiated materials.

V. THERMOPHYSICAL PROPERTIES

The thermal properties of materials are characterized by the coefficient of thermal conductivity λ, the specific heat capacity C, the coefficient of thermal diffusivity a, the coefficients of linear β and volume α thermal expansion and the density ρ. The melting temperature T_m and the degree of crystallinity X are introduced for partially crystalline polymers.
The Database contains 76 records on the thermophysical properties of the irradiated materials.

VI. GASEOUS PRODUCTS

The data on the composition of the gaseous products presented in this Database have been for the most part obtained by the gas chromatograph-mass-spectrometer system.

1. **The measure of the quantity of evolved gaseous products is given by the radiation-chemical yield G, which is the number of molecules produced per 100 eV of radiation energy absorbed.**
2. **The Database also gives the values of the mass and volume of the evolved gas per unit of the sample mass under normal pressure.**

The ampoule technique was used for obtaining the data on radiation-induced gas evolution. The procedure is as follows: the samples are inserted into an ampoule (glass, quartz or metallic) which is then evacuated and then filled with the required gas. The ampoule is then sealed and irradiated. After irradiation, the pressure of the gaseous products and their content is measured.

The Database contains 247 records on gas evolution.

VII. MASS LOSS

The following technique was used to determine the radiation-induced mass loss: the initial weight of the sample was determined; the sample was then inserted into an ampoule and the ampoule was evacuated for several days. After this, the sample was weighed again under atmospheric pressure. Then the ampoule with the sample was evacuated again and the sample was irradiated in vacuum. After irradiation, the sample was weighed.

The Database contains 35 records on mass loss.

The Database presented has 2016 records. The per cent distribution of the groups of properties in each of the material types is given in the histogram (see file Diagr.xls).

STRUCTURE OF THE DATABASE

The kernel of the Database consists of five interrelated tables.

1. **Table containing the list of materials, giving the brand of each material, its chemical base, type of the material and the production standard for the material.**
2. **Table of the types of materials.**
3. **Table of the groups of properties.**
4. **Table of the types of radiation.**
5. **Table of the test results, containing the name of the material, the type of the material, the group of properties, the irradiation type, the dose rate, the temperature of irradiation, the irradiation environment and the field of the embedded OLE object (tables and graphics).**

The following has been done to ensure maximum user comfort while working with the

Database:

1. The main click form was created. It is loaded immediately on the opening of the Database. The click form allows to open all the tables;

2. Five forms have been created, based on the above-mentioned tables, which can be also opened from the main click form;

3. A group of macros has been created for linking the forms and selecting data.

A statistical analysis of the contents of the Database is presented in the histograms (see. file Diagr.xls).

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"The contractor, Karpov Institute of Physical Chemistry, hereby declares that, to the best of its knowledge and belief, the technical data delivered herewith under Contract N F61775-99-WE058 is complete, accurate, and complies with all requirements of the contract"

Date: **June, 20, 2000**

Name and Title of Authorized Official:
Director of Space material science Department Dr. S. Khatipov

"I certify that there were no subject inventions to declare as defined in FAR 52.227-13, during the performance of this contract"

Date: **June, 20, 2000**

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