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Problems of Designing Radioisotope Thermoelectric Power Generators with a Service Life of Decades for Use in Outer Space Exploration Vehicles

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Abstract—The present work deals with the feasibility of developing a radioisotope thermoelectric power generator (RTPG) capable of operating unattended in outer space over a period of several decades, among other things, on the basis of chemical compounds that occur in meteoric matter. The possibilities for solving problems related to the production of three-dimensional materials and to thermoelement interconnections are discussed. The implementation of nanotechnology will allow one to achieve an increase in the efficiency of a RTPG by 15% and higher.

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One of the objectives of the Federal Space Program of Russia for the years 2006–2015 and beyond is the development of fundamental space exploration of the moon, the nearest planets and their satellites, and other celestial bodies in the solar system. These explorations require a reliable power supply for the scientific and research equipment on board the space vehicles. In circumterrestrial space this problem can be solved by implementing solar batteries or fuel cells, while under conditions of outer space, the power supply can only be provided by means of the use of nuclear power and, in particular, radioisotope thermoelectric power generators (RTPG) [1].

RTPGs based on an oxide of ^{238}Pu, which have been developed in the USA within the framework of the Systems for Nuclear Auxiliary Power (SNAP) program, provided long-term power supply of a number of exploration space vehicles, including *Cassini*, with a lifetime of more than 20 years. However, this lifetime is not sufficient for missions of exploratory space probes beyond the confines of the solar system.

Heat sources in the form of ^{238}Pu and ^{232}U isotopes, with half-lives of 87.7 and 68.9 years, correspondingly, can provide an adequate amount of heat during the required time.

However, production of electric power in the required amount by means of thermoelectric conversion in thermopiles made of thermoelectric materials used nowadays cannot be assured for a number of reasons.

The modern, most efficient thermoelectric materials are made of semiconductor alloys containing tellurium, germanium, and selenium, which exhibit high vapor tension, and at high temperatures sublimate from the legs. Foreign specialists have carried out investigations of thermoelectric materials based on selenides that have operated over 50000 hours at a temperature of 573–1073 K; as a result of these efforts, it was found that a leg of the *p*-type lost on the average 1.6 g in 8000 hours due to sublimation, first and foremost, of selenium. Similar investigations have been carried out on thermoelectric power generators with the legs of thermoelectric cells made of PbTe, PbMnSnTe, AgSnTe, BiSbTe, and SiGe; these thermoelectric power generators have been tested under vacuum and in an inert medium for 700 000 hours. These tests showed that the electric power output of thermoelectric power generators decrease, at an average rate for the entire trial period, by 0.22-0.62% in 1000 hours. The main reasons for the degradation of output parameters of thermoelectric power generators were sublimation of leg material, oxidation of the legs due to the loss of sealing of the generator shell, and, as a consequence, deterioration of the properties of thermoelectric materials.

As the results of investigations show, even the use of high-temperature thermoelectric materials made of SiGe alloy does not assure stable output parameters at a lifetime lasting decades. For example, the battery (Fig. 1a) with the legs made of the SiGe alloy without antisublimation coating, which was used in the first Soviet *Orion-1* and *Orion-2* space RTPGs, was able to provide a stable continuous lifetime of only around 3000 h.