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Space Nuclear Power Systems: Yesterday, Today, and Tomorrow

V. N. Akimov, A. A. Koroteev, and A. S. Koroteev

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Abstract—The present work deals with issues related to the development of space nuclear power systems that offer great potential for increasing the effectiveness of space activities.

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INTRODUCTION

One of the determining trends in the development of rocket and space technology is the increasingly more stringent requirements on the level of the power supply of space vehicles. Among modern automatic spacecraft, geosynchronous telecommunication spacecraft have the greatest power availability (up to 20–25 kW.) As of today, almost all of them (except spacecraft for deep space exploration) use solar power plants. However, the low density of solar radiant energy and ensuing overall dimensions of solar cell batteries, as well as the necessity for using heavy weight power storage units on shadowed portions of the orbit, restrict the possibilities of increasing the electrical output of solar power plants up to tens and hundreds of kilowatts. It is only possible to increase the effectiveness of space activities by introducing nuclear power plants intended for space application. Such nuclear power plants are characterized by compactness, independence of generating capacity from the distance of a spacecraft to the Sun and illumination conditions, they exhibit enhanced radiation resistance, as well as are superior to solar power plants in their specific mass characteristics at a level of electric power output exceeding 50 kW.

Stages in the development of space nuclear power plants in Russia and in the USA. Russia is the country that has amassed the greatest experience in developing and operating nuclear power plants for space application. Works in the field of space nuclear power technology began in our country in the early 1960s [1]. Between 1970 and 1988, 32 spacecrafts equipped with thermoelectric nuclear power reactors were launched (Fig. 1a).

Concurrently with the development of the Bouk thermoelectric nuclear power plant, in the USSR, there were extended works on developing nuclear power systems based on thermionic power converters (Fig. 1b) that are integrated into the reactor core and have higher efficiency as compared to those of thermoelectric converters (Topaz nuclear power plant).

In the USA in the years 1956–1970, according to the Systems for Nuclear Auxiliary Power (SNAP) program, reactor power plants SNAP-10A, SNAP-2, and SNAP-8 were developed having electric power output 0.5 kW, 10 kW, and 30 kW, respectively, equipped with the thermoelectric (SNAP-10) and dynamic (SNAP-2, SNAP-8) systems of power conversion. The spacecraft equipped with a SNAP-10 power plant was launched into space on April 3, 1965, and it became the only American spacecraft equipped with a nuclear power plant. After 43 days of operation, the nuclear power plant failed. In the 1980s works on the SP-100 project (the development of a 100 kW nuclear power plant) were initiated, with the prospects for its increasing up to 1000 kW, for application in spacecraft that were developed in those years within the framework of the "Strategic Defense Initiative" program. This project was closed in 1993 because of cutback in financing.

In parallel with the efforts to develop nuclear power plants for space application, in the USSR and the USA, large-scale projects and design works on designing nuclear rocket engines for space launch vehicles were carried out. In the USA, the experimental reactor for the Kiwi nuclear rocket engine and the aircraft version of the Nuclear Engine for Rocket Vehicle Application (NERVA), were developed and tested. Since financial expenditures were focused on the "Moon Program," and there were no ideas of implementing nuclear rocket engines in the near future, the relevant program was closed in 1973. In the USSR, in 1958 at the Semipalatinsk nuclear test site, construction of the pulse graphite reactor and the test rig facility for loop tests of fuel assemblies began. In 1964 at the same place, construction of the base for testing nuclear rocket engines—the Baikal test-rig complex—began. By that time the priority task was the development of an IR-20-100 experimental reactor with minimum overall dimensions, and, on its basis, an aircraft nuclear rocket engine of the 11B91 type with thrust of 3.6 t for use as part of a jet-assisted take-off unit. A large scope of experimental investigations had been carried out, and by the early 1980s, several series of static test firings of a nuclear rocket engine had been conducted [2].

However, in the early 1980s it became evident that, for a number of reasons, the nuclear rocket engine