

# Chapter 1

## History Creation of a Nuclear Rocket Engine Reactor

The high pace of development and the high scientific and technological level of atomic power engineering achieved in the USSR in the second half of the 1950s created objective prerequisites for the construction of fundamentally new types of stationary and mobile nuclear energy reactors and facilities intended, in particular, for cosmic purposes, such as nuclear rocket engines (NREs) and small-size nuclear-electric energy converters [1, 2].

The development of NREs in the USSR was initiated in 1955 when I. V. Kurchatov, S. P. Korolev, and M. V. Keldysh met to discuss the possibility of creating a rocket with an atomic engine to enhance the defensive power of the country in response to the Rover program for developing NREs, started in the USA (Fig. 1.1).

In 1956 and 1958, two government acts for the development of work with the aim of building nuclear rocket engines were signed in the USSR [2]. At this stage, preliminary design work was started to create a mounting base for testing NREs, and material technology investigations were initiated. The heat exchange and hydrodynamic conditions were studied at Research Institute-1 [currently, Research Institute of Thermal Processes by V. M. Ievlev (RITP)]. Studies in the field of neutron physics and reactor control were performed at the Obninsk Physical Energy Institute (PEI) and at the Kurchatov' Atomic Energy Institute (AEI). The technology of refractory materials and heat-releasing elements (HREs) was developed at Research Institute-9 (currently, the A. A. Bochvar All-Union Research Institute of Inorganic Materials, ARIIM). The problems of selecting materials for NREs based on carbides of transition metals and graphite in gas media were also partially investigated, beginning from the 1960s, at the All-Union Institute of Aviation Materials (AIAM), the State Institute of Applied Chemistry (SIAC), the Institute of High Temperatures (IHT), the Graphite Research Institute, and the Ceramics Department of the Leningrad Technological Institute.

In 1957, researchers at the RITP proposed a principle of refining individual elements of units of the NRE reactor on electrothermal and plasmatron mounts, which reduced the extent of reactor tests. Different NRE schemes were considered. The simplest NRE with a reactor with a solid-state core (named the A scheme) can produce



**Fig. 1.1** From *left to right*: Academicians of Science academy of the USSR, the main designer of ballistic missiles S. P. Korolev, the main supervisor of a nuclear studies problem I. V. Kurchatov, president of Science academy of the USSR M. V. Keldysh

a thrust 450 s. The NRE with a gas-phase reactor (the B scheme) could produce a specific thrust up to 2,000 s, but problems to be solved in its construction, namely, the confinement of a uranium plasma with the temperature up walls of a heat-releasing assembly (HRA) from the plasma, were much more severe than those in the construction of the A scheme. It was decided to begin the development of the A scheme (while the work related to the B scheme was continued as a research study).

Within 2 years, two teams were actively involved in the development of the first NREs. A ground-based IVG-1 (research high-temperature gas-cooled) reactor, a prototype of an in-flight NRE version, was developed at the Research and Development Institute of Energy Technology (RDIET) headed by N. A. Dollezhal' and at AEI under the supervision of N. N. Ponomarev-Stepnoi. The second team developing a ground-based IR-100 engine was headed by V. M. Ievlev, the scientific chief of RITP, A. D. Konopatov, the chief designer of the engine at the Development Laboratory of Chemical Automation (DLCA), Voronezh, and V. Ya. Pupko, the scientific chief of the reactor at the Physical Energy Institute (PEI), Obninsk. The first carbide-based HREs were proposed and manufactured at Research Institute-9. The expansion of NRE studies required the manufacture of a great number of HREs for experimental HRAs. In August 1962, the Ministry of Medium Machine Building of the USSR decided to create the Research Institute of Heat Releasing Elements (RIHRE) [currently, the "Luch" Research and Production Association (RPA), a Federal State Unitary Enterprise (FSUE)] with an experimental plant providing technological possibilities for the rapid complex development and production of new types of nuclear fuel and HREs [2]. This resolution was preceded by the very important decision of 30 December 1959 about the inexpediency of further developments of military

nuclear ballistic rockets (due to progress in the development of chemical-fuel engines) and the necessity of continuing NRE developments for space launchers [1].

The basic challenge encountered by the developers of NREs was to prevent damage to the ceramic active core and, most of all, HREs caused by thermal stresses. It is known that thermal stresses are proportional to the product of the energy-release density, the elastic modulus of the material, the linear expansion coefficient, and the square of the characteristic transverse size of the construction. The energy release cannot be strongly reduced because such a reduction would result in an increase in the reactor weight with protection and would reduce the NRE advantages to a minimum. Reducing the HRE characteristic size can be done efficiently, but this is restricted by the fact that elements of very small sizes would be severely damaged by vibrational stresses, which are significant in rocket engines. In this case, the limiting characteristic transverse size of HREs is 2–3 mm. An alternative to the carbide HRE is the graphite HRE. Graphite has a unique thermal strength because its elastic modulus is almost two orders of magnitude smaller than that of carbides. However, a substantial disadvantage of graphite is that it quite actively interacts with hydrogen (everything comes at a price).

Unlike American scientists, Soviet researchers began to develop the NRE core using HREs made not of graphite, which is thermally stable but unstable in the hydrogen medium, but of carbides, which are brittle but are more stable in hydrogen [2]. While in many other scientific fields Soviet scientists had to ‘overtake’ foreign investigations, the NRE was developed without blindly copying ‘foreign’ samples, the experience of predecessors being critically analyzed. Soviet researchers decided (correctly, as the result showed) that protecting HREs from interaction with hydrogen is more difficult than providing its acceptable thermal strength resistance. Although graphite HREs was also developed in the USSR, they were regarded as a backup.

In 1962–1969, under the supervision of M. V. Yakutovich, director of the RIPRA, the material technology, technological, theoretical, and test departments were created to solve the following problems [2]:

- selection of the fuel and construction materials for NREs;
- development of the technological foundations for manufacturing devices from these materials;
- construction and computational and experimental demonstration of the efficiency of elements of the active core; preparation of project documentation and organization of semicommercial production.

These problems were successfully solved by using a systematic and complex approach. Detailed theoretical estimates of the operational conditions of the devices, the required technological studies of the properties of materials, and the working out of technological versions were realized in the form of technological chains developed together with the experimental plant. In turn, experimental and test samples of devices were subjected to thermal, hydraulic, and resource tests in the IVG reactor located on the nuclear proving ground “BAIKAL-1” in the Semipalatinsk region (town Semipalatinsk-21, later Kurchatov, Kazakhstan). The working area “BAIKAL-1”

**Fig. 1.2** Director of the RIPRA “LUCH”, Doctor of Science, laureate of many state prize M. V. Yakutovich (10.08.1902–29.06.1988)



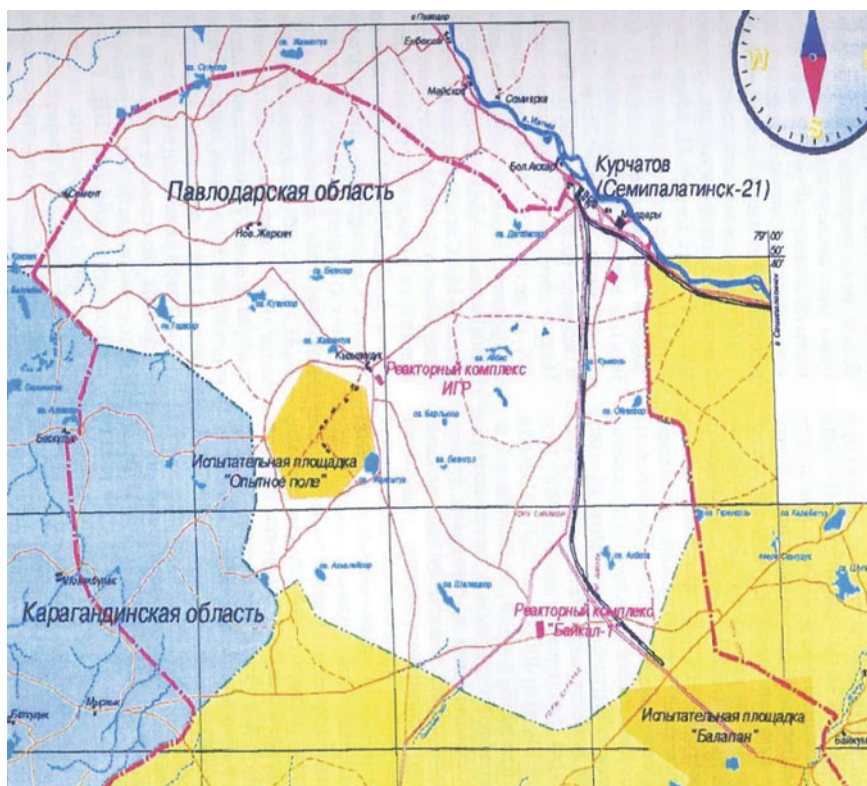
is situated at 70 km from inhabited town Kurchatov and at 150 km from the Semipalatinsk town (Figs. 1.2–1.4).

This paper is devoted to the history of material technology developments for manufacturing elements for the NRE reactor core at Research Institute of Production Research Association [RIPRA] Federal State Unitary Enterprise (FSUE) “Luch” from 1962 to 1991. Because the results of NRE studies are scattered over numerous publications in periodicals or special collections of papers that are not easily accessible, we decided to generalize the data on the characteristics of the materials and the efficiency of elements of the NRE core in this paper.

Clearly, the scope of problems considered here is limited. For example, we do not discuss issues concerning the design and the radiation and thermal protection of the nuclear engine, or the neutron-physical and hydrodynamic characteristics of the reactor. These issues were partially considered in the book *Nuclear Rocket Engines* published in 2001 [1].

Because of the high brittleness of the materials based on interstitial phases (carbides and hydrides), which are used in construction, special attention is paid in manufacturing active-core elements that are stable under the action of high thermal and neutron fluxes, stresses, aggressive gas media, and ultrahigh temperatures. Such a variety of operating parameters required the development of a number of new pre-reactor physic-mechanical methods for testing materials at the RIPRA “Luch”, where diffusion-controlled processes (creep, corrosion, and radiation) were investigated in fuel and construction materials based on interstitial phases.

Beginning from 1976, HRAs developed for NREs were tested in the IVG-1 reactor, which was used to work out the elements of the reactor core. Later, a mount was constructed for testing an ‘engine’ version of the IR-100 reactor, which was tested for several years at different powers and was then converted into a material technology research low-power reactor, which is still working successfully till date.



**Fig. 1.3** The map of the Semipalatinsk region (Kazakhstan)

In the late 1970s and early 1980s RITP and RDIET have commenced an intensive work on developing a multimodal system [3] capable of producing both jet thrust and electricity to power life support systems of the spacecraft. Besides the main nuclear propulsion mode, the NRE was to be operating at two generation modes: low-power mode for prolonged operation (several years), and high-power mode for half of the specified service life in the propulsion mode. The high-power mode (HPM) presented no particular problems for the reactor. At low-power mode (LPM), the heat transfer agent circulates only outside the NFA casing, while the heat from fuel rods is transferred to the casing by radiation through the thermal insulation. Such mode differs significantly from the propulsion mode, the former involving considerable temperature gradient across the NFA radius and uranium burnout (min. 3–5 %). Therefore, the applicability of the structural NFA parts and fuel rods under these conditions demands further research. First of all, the design and processing technology of the fuel rods should guarantee retention of fission products inside the rod for several years at temperatures of 2,000 K under high vacuum or in H-containing working fluids at pressures of 0.1–0.2 bars.



**Fig. 1.4** Town Semipalatinsk-21, later Kurchatov on the river Irtysh, Kazakhstan

Started almost five decades ago, the program for development of nuclear rocket engine (NRE) originally based on the political aims and priorities of conducting Cold War between the USSR and the US were suspended in the early 1990s due to the USSR having stopped funding of these works.

The main output of the Soviet nuclear rocket engine (NRE) program from the initial 60x years becomes the technological and experimental possibility of the ceramic active zone creation of the NRE for hydrogen heating at the maximum parameters values: A hydrogen reheat at temperature up to 3,100 K; power fuel density to 35 MW/l; duration of tests to 4,000 s; the maximum heating/cooling rates of fuel elements to 400/1,000 K/s

The results of numerous studies performed at the RIPRA “Luch” for many years allowed constructing a scientific system of knowledge about the nature of refractory compounds, mechanisms of their deformation and damage, and the features of their behavior in construction and fuel hardware during variation of the operational parameters of reactors. Many developments at the RIPRA “Luch” have been acknowledged at international conferences, symposia, and exhibitions. A group of scientists has grown who have defended more than 30 Doctor of Science and 200 Ph.D. dissertations and published a few dozen monographs and a few hundred scientific papers on high-temperature materials and their applications. Some researchers became laureates of State Prizes of the USSR and Government Prizes and received titles of Honored Scientist, Honored Technologist, and Honored Inventor.

The workings out of NRE begun almost half a century ago caused, in due time, by political problems and priorities in conducting “cold war” between the USSR and the USA were suspended in the early 1990s in connection with the financing termination in the USSR.

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