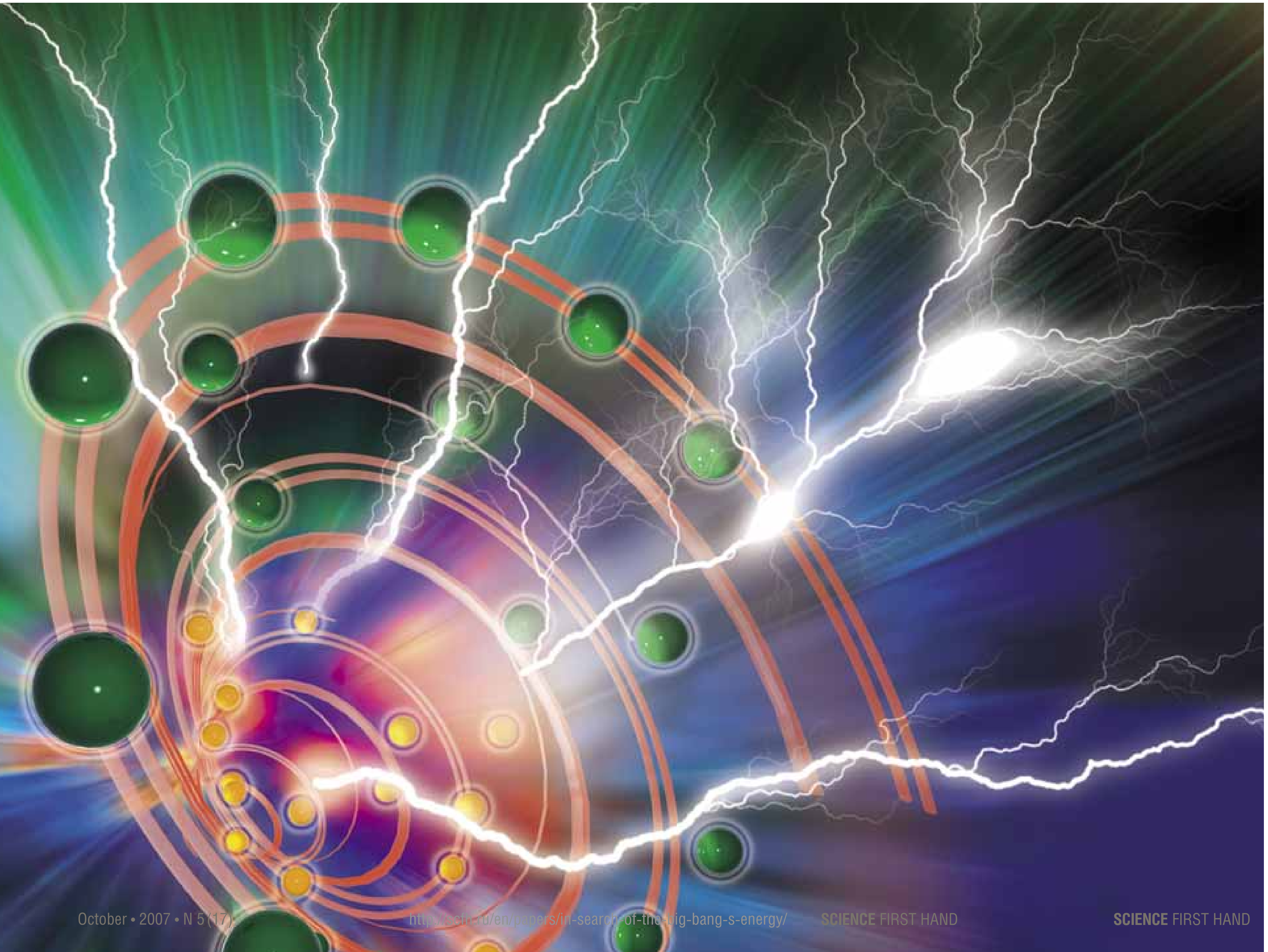
M.A. GRACHEV

IN SEARCH OF THE BIG BANG'S ENERGY



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All the chemical elements have formed as a result of compression of the universe after the Big Bang. Protons and neutrons joined to make up more or less stable combinations. Unstable combinations gave rise to radioactive elements, which by now have decayed or were preserved in minor quantities. Natural radioactive substances release the energy of the Big Bang, much as fire releases energy of fuels — energy of Sun's light accumulated over the previous geological epochs. Nuclear energy released as a result of radioactive decay is many orders of magnitude higher than the energy released in chemical burning — a fact well-known since the late 19th century — however, its wide practical application was not feasible because the rate of radioactive decay of nuclei is not sensitive to environmental influences like pressure, temperature, or attack by chemical reagents, i. e., it cannot be switched on and off at will.

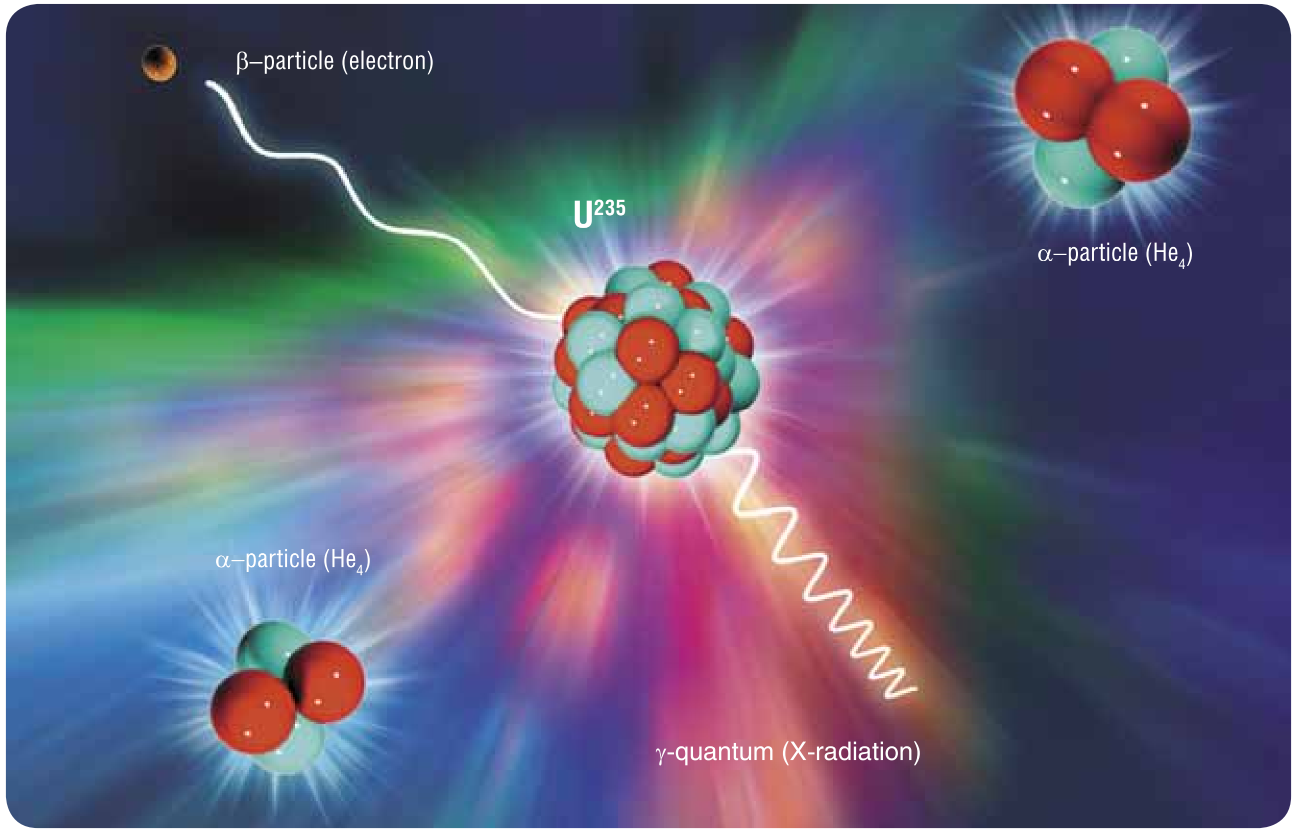
The situation changed dramatically in the late 1930s, when the nuclear reaction of uranium fission was discovered. Uranium nucleus, like a big drop, is unstable and readily falls into two approximately equal parts when hit by an accidental neutron. Most importantly, such fission gives rise to a few new neutrons. Hitting the nucleus of a neighboring atom of uranium, the neutron makes it split, and a few more neutrons appear. Each of them hits a new nucleus, causing its fission. The reaction of decay is similar to an avalanche: a huge amount of energy stored at the time of the Big Bang is released, and this energy can be managed through regulating the flux of neutrons. If a lot of uranium (several kilograms) is quickly accumulated in one place (critical mass), a nuclear explosion will occur. If uranium is fed into a nuclear stove piece-by-piece, it will "burn" slowly: heat will be released progressively, and we will have a nuclear power heat station.

Nuclear physicists realized immediately that uranium could be used to make an absolute weapon: an atomic bomb. When exploded, a few dozens kilograms of uranium will release an energy that amounts to a few thousand tons of trotyl.

Luckily for mankind, which was on the brink of the Second World War, it turned out that only one isotope of uranium — uranium 235 — can decay in the way described above, and its content in the naturally occurring mixture of isotopes is very low (about 0.7%). It was impossible to make an atomic bomb out of native uranium — it had to be enriched so as to increase the content of uranium-235. It was this extremely complicated problem that was solved by the participants of the international Manhattan Project initiated in 1939 by Albert Einstein. The aim was to make an atomic bomb before the Hitler Germany managed to make it. The project's outcome was bombing Hiroshima and Nagasaki, and monopoly of the West on the atomic weapons.

Native uranium is a mixture of three isotopes: 238, 235, and 234. Its average content by mass in the earth's crust is a little over 2/10,000. Pure uranium looks like a piece of steel, but is heavier than any other metal (d=18—19 g/cm^3); it can be easily processed; and powdered uranium burns well in the air. Unlike harmless steel, however, it is a strong chemical and radioactive poison

Uranium radioactive decay



In 1945, immediately after the World War was over, a cold war broke out. The USA drew up a list of 18 cities of the Soviet Union on which atomic bombs were to be dropped. By 1949, the number of cities on the list increased to a hundred.

I got acquainted with the atomic problem at the age of six. In August 1945, when Americans dropped atomic bombs on Japan, I asked my father, "Daddy, please tell me, does Stalin have such a bomb?" And father replied, "Sure, sonny, don't worry." However, Stalin had no atomic bomb at that time. It was made later, in 1949, and the first Soviet tests were carried out. Up to that moment, the world was on the brink of a nuclear catastrophe. Our country, at least, was in danger of total democratization on radioactive ashes.

Who knows what course the world history would have followed if in 1949 the USSR had not tested its atomic weapons? Nuclear physicists from abroad, risking their own lives, contributed to the creation of an atomic bomb in the USSR because they understood that world monopoly on atomic arms had to be avoided at all costs. The USSR population came under a grave threat — and Soviet scientists and engineers realized it perfectly well. It was their heroic efforts that gave birth to the Soviet atomic industry. I am firmly convinced that it was the enormous enthusiasm and great responsibility shouldered by the people who created atomic industry in the Soviet Union that made it possible to escape war. That war could have been nothing else but nuclear; and American atomic arms turned out to have a counterpart. This is why a nuclear war did not break out after all. I think this was a major factor in the development of modern civilization.

An average heat power station using ordinary coal as the raw material emits in the air, together with fly ash, over 500 kilograms of uranium per year; whereas the Angarsk Electrolysis Chemical Complex emits not more than 15 kilograms of uranium per year

Air which contacts within the plant with any sources of uranium is collected by a high-power centralized ventilation system and directed to special absorption towers where uranium is removed. Polluted air at first contacts saw dust placed on special shelves where this dust is continuously mixed. Uranium has a high affinity to organic matter, and is strongly bound by saw dust. Dust saturated with uranium is burnt to recover the element from the ash. After exhaust air leaves the saw-dust tower, it is directed to another tower where it contacts a solution of soda which removes the last traces of uranium

Centrifuge watching over the peace

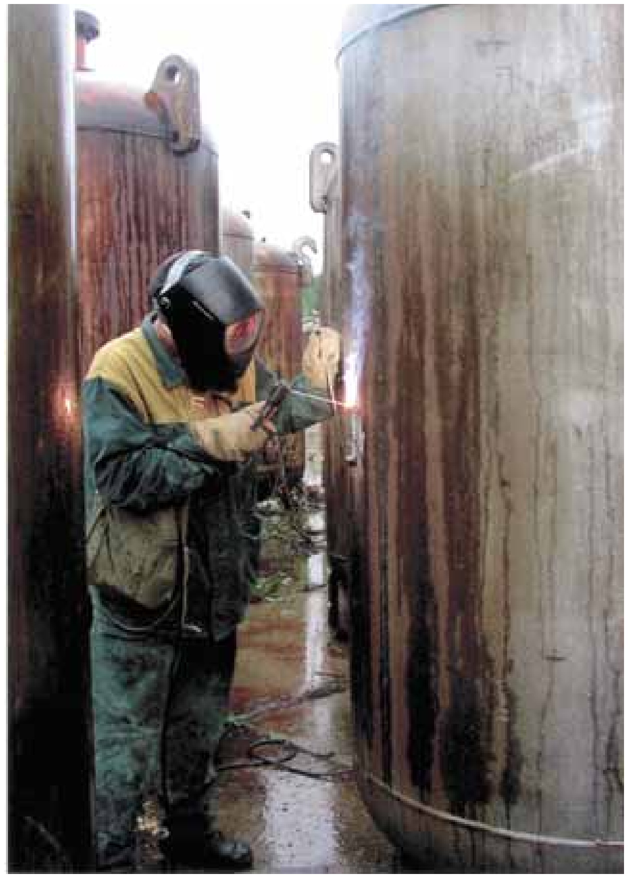
The decision to construct the Angarsk Electrolysis Chemical Complex (AECC) — a producer of enriched uranium-235 — was made in 1954. In 1957 the AECC was put into operation and produced its first enriched uranium.

Underlying the separation of uranium isotopes is a small difference in the atomic mass (235 and 238 atomic units). To separate the isotopes, uranium is transformed into gaseous hexafluoride. Lighter molecules of uranium-235 hexafluoride diffuse more easily through microscopic holes of special porous membranes.

Successively pushing the gas through a cascade of many thousands of membranes, it is possible to obtain hexafluoride of pure uranium-235 separated from uranium-238. This diffusion technology was implemented in the Manhattan Project, and later in Angarsk. It is hard to imagine how

Separation of ^{235}U and ^{238}U isotopes in centrifuges.
Gas flows of enriched and depleted uranium hexafluoride are directed by ducts around the cascade of centrifuges which work as a united system having an efficiency close to 100%

Since the end of the 19th century, many potential methods for the separation of isotopes have been proposed. Among them was separation in a centrifuge. This option was thoroughly considered during the Manhattan Project (at the beginning of the 1940s) with respect to isotopes of uranium, but rejected because of the technical complexity. In 1951, the USSR authorities ordered to stop this research. However, already in July 1952 a decision was issued to resume development of separation of uranium isotopes by means of centrifugation. This was due to a remarkable success of Soviet engineers who had proposed a promising prototype of the machine. Finally, in 1959 the Ministry approved drawings and other documentation for mass production of the gas centrifuge VT- 3F



A special kind of solid waste produced by the AECC is uranium hexafluoride (UHF) depleted in isotope ^{235}U. It is kept in steel containers in a special area in the open air on the territory of the Complex. Depleted UHF is considered to be a potential raw material for the future power industry, and is therefore treated as a national reserve. On extremely rare occasions, cracks may form, through which uranium hexafluoride can leak. A crack, however, is quickly filled with uranyl fluoride; the crack is sealed by welding without emptying the container, which is then returned to the plant for unloading

In order to ensure that the personnel will be able to act appropriately in case of an incident, training is held regularly according to the in-house regulations developed at the Complex

Separation of uranium isotopes by means of diffusion takes about 5% of the energy which could be produced at a nuclear power plant of enriched uranium, separation by means of centrifugation reduces this amount to 0.1%
(From foreign press)

people managed to set up such a sophisticated diffusion plant in a country ruined by a recent war, and in the remote Siberia...

At the dawn of the atomic age, uranium isotopes separation in a centrifuge was considered alongside diffusion separation. In the centrifuge's rotor, molecules of uranium hexafluoride with the heavy uranium isotope concentrate closer to the rotor wall than molecules with the light isotope. By using many centrifuges united into a cascade, one can obtain enriched uranium-235 hexafluoride. The principle of separation is simple but its implementation is difficult. To ensure isotopes separation, the rotor must revolve at a very high speed (1,500 revolutions per second). Acceleration in this case equals several hundred thousands accelerations of the Earth's gravity, and the rotor experiences a heavy mechanical load. Soviet engineers developed rotor suspension systems and special-purpose extra strong materials. Mass-scale production of gas centrifuges was established. In the 1990s, the AECC completely switched to the progressive, energy-saving centrifuge technology.

Ecological audit of the AECC

In 2006, news spread that Russia was going to set up an International Uranium Enrichment Centre. Since Iran, reportedly, desired to develop an uranium enrichment program of its own, and the world community felt concerned that Iran might develop atomic weapons, an idea appeared to organize a center, in Russia, that would supply enriched uranium to all peaceful nuclear energy producers who promised not to enrich uranium themselves. As the Center was supposed to be based in Angarsk, I realized that I would not be able to ignore this problem because it was important for the development of the Irkutsk Oblast. Moreover, the Limnological Institute, thanks to its research in the paleoclimatology and geochemistry of uranium in Lake Baikal, had gained good experience in measuring low concentrations of uranium and its isotopes in natural environments.

It goes without saying that the plans of creating the International Uranium Enrichment Centre made the community deeply concerned about atomic safety. I can say about myself that I am afraid of the same things that other people are. Even though it was secret, I knew what the Angarsk Electrolysis Chemical Complex did: it produced enriched uranium. What I did not know was what kind of uranium it made and how exactly this was done. And, of course, I felt somewhat anxious.

There is a saying that a sleeping mind gives birth to monsters. It was necessary to wake up the mind.

Our interests coincided with those of the Complex, which had to explain to the community what it was doing, what it was going to do and how safe it was for the environment and people.

Hence, we decided to perform an ecological audit of the AECC. In contrast to an ecological study, the audit was mostly based not on our own data obtained in our laboratories but on the evidence provided by other bodies — the Complex itself and its inspecting authorities — and our task was to check these data for consistency. The Complex disclosed dozens of volumes of formerly secret documentation. It was an enormous amount of papers, and our task was hard.

As for the results of our work, they are as follows.

The Complex is not outstandingly hazardous for the environment. For instance, its largest waste into the air is the discharge of ammonia. It amounts to several dozen tons a year, which is far less than the ammonia discharge from the neighboring poultry farm. As for uranium, its discharge is negligible (only about 16 kilograms a year), thanks to its efficient removal by a special sophisticated system. For comparison, a large coal-burning power station discharges about 1,000 kilograms of uranium per year. The AECC does not pollute water because fresh water is used exclusively to cool closed equipment circuits, water does not contact directly any dangerous chemicals. The AECC does not discharge substantial quantities of heavy metals or other ecologically toxic agents. Summing up, to our own surprise, we came to the conclusion that the Angarsk Electrolysis Chemical Complex was among the most ecologically safe companies of the region. This conclusion was substantiated by selected control measurements performed by our laboratories.

One kind of the solid waste produced by the AECC — 235 isotope-depleted uranium hexafluoride — caused deep concern of the environmentalists. This so-called depleted UHF is formed during enrichment. It is stored in a special-purpose area on the territory of the AECC. The problem of utilizing depleted uranium hexafluoride is not yet finally solved in the world — it is stored as UF_6 in a similar way in all the countries producing enriched uranium. In the future (say, in three decades), depleted uranium may find application as nuclear fuel in the so-called fast neutron reactors, and hence is regarded as a national reserve.

The AECC keeps depleted UHF in steel containers in the open air. If moisture has no access to the substance, it remains stable and does not give rise to a high pressure inside the containers (at room temperature, excessive pressure is below 0.1 atmospheres). The pressure becomes equal to the atmospheric one at the sublimation temperature which is 56.5 °C. Uranium hexafluoride stored at the AECC can pollute the environment only under exceptional circumstances, if a container breaks and gives access to atmospheric moisture. When interacting with moisture, uranium hexafluoride turns into low-volatile uranyl fluoride and volatile hydrogen fluoride:

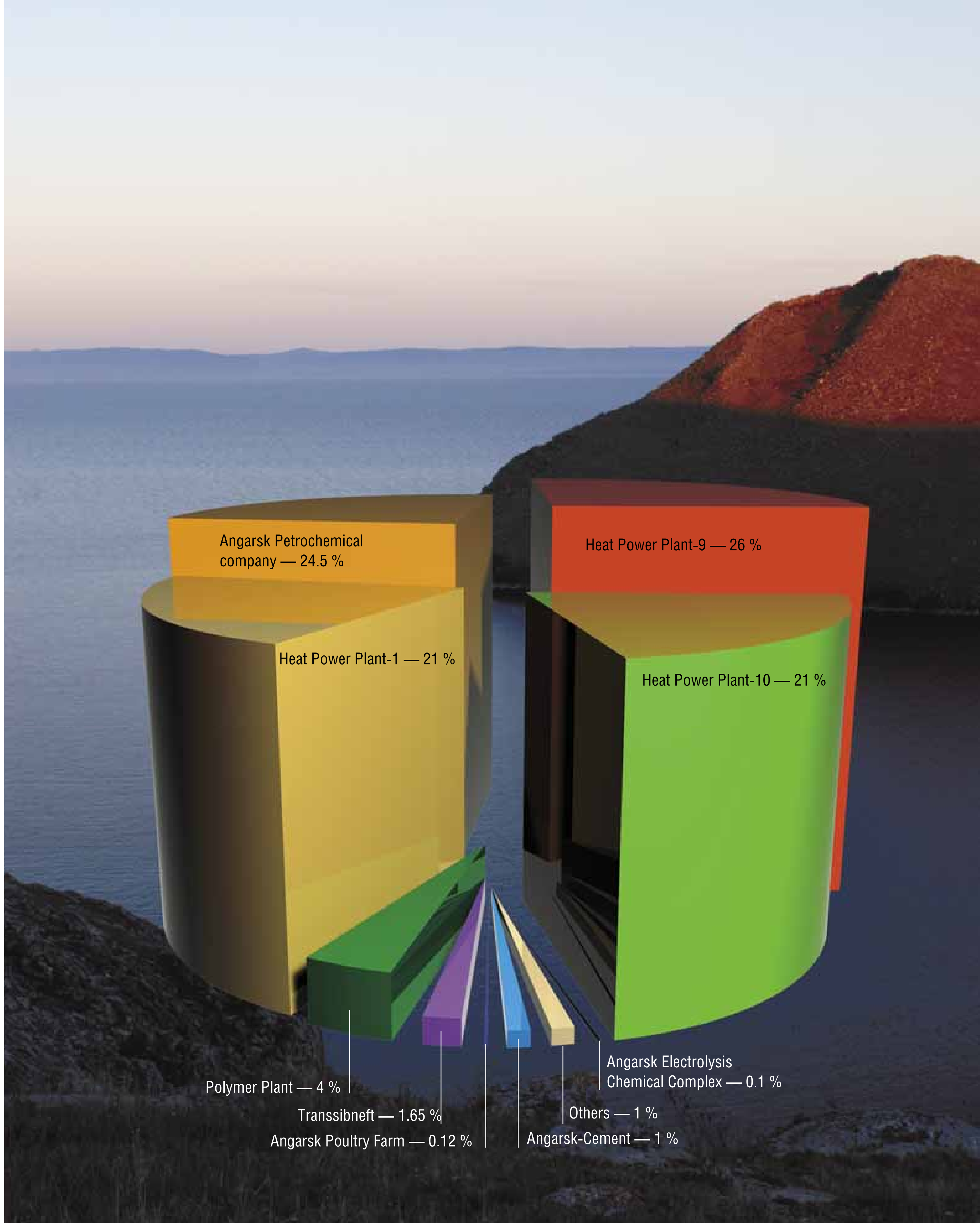
$$UF_6 + 2H_2O = (UO_2)F_2 + 4\ HF$$

In a force majeure situation, only hydrogen fluoride can escape the Complex's territory.

Uranium hexafluoride containers are checked daily by the personnel. On very rare occasions, cracks may form at welds, through which uranium hexafluoride leaks outside. This, however, does not have any hazardous consequences because the crack is quickly "blocked up" with uranyl fluoride. In such situations, the crack is sealed by electric welding on the spot, without unloading uranium hexafluoride, and the container is then returned to the plant to be emptied. In case one or several containers are completely ruined, emergency measures aimed at eliminating hazardous results have been developed and are regularly checked by training.

A technology for turning uranium hexafluoride into low-volatile and moisture-proof uranium tetrafluoride is under development and will soon be implemented at the AECC.

Decisions have been made to develop the AECC and to increase its production so as to satisfy the needs of nuclear power industry. Other countries are also going to increase the production of enriched uranium. Evaluation of such projects from the environmental viewpoint is a must. It should be said to the credit of the AECC's management and industry as a whole that, judging from the way we communicated during the ecological audit, they are open for co-operation.



Angarsk companies' share
in atmospheric discharge