РОСАТОМ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

НИКИЭТ им.Н.А.Доллежаля

Nuclear explosive technologies for peaceful nuclear explosions

A.P. Vasiliev, Chief Research Scientist
at JSC NIKIET (Moscow),
Member of Public Council of ROSATOM
State Corporation

Benefits of peaceful nuclear explosions:

- unit cost of a peaceful nuclear explosion is significantly lower than that of a chemical explosive, and is weakly dependent of its energy release;

- low cost of placing;

- reusability of wells.

On May 16, 1950, I.V. Stalin signed a special order of the Council of Ministers of the USSR “Research and development, design and experimental works on peaceful use of atomic energy”;

On December 8, 1953, D. Eisenhower said in his speech before the UN:

“This greatest of destructive forces can be developed into a great boon, for the benefit of all mankind”;

I.V. Kurchatov said at the session of the Supreme Soviet of the USSR: “Let the atom be a worker, not a soldier!”

- In the summer of 1957, the Plowshare Program for nonmilitary use of nuclear explosions was established;
- September 19, 1957, the Nevada Test Site: the first fully contained underground detonation, the Rainier test (E=1.7 kt, h=274 m) was carried out;
- December 10, 1961, outside of the Nevada Test Site: the Gnome test (E=3.1 kt, h=361 m) was performed in salt;
- In total, 12 detonations, with 4 of them outside the test site, and 16 charge tests (9 for clean charges) were conducted.

- January 15, 1965, the Semipalatinsk Test Site: the Chagan explosion with the aim of water storage reservoir construction (E=140 kt, h=178 m, fusion/fission ratio of 95 %) was conducted;
- 1965: first peaceful explosions outside test sites with the aim of oil production stimulation at the Grachevsky oil deposit, Bashkiria;
- 1973-1988: Program No.7 “Nuclear explosions for national economy”;
- In total, 124 explosions were conducted (135 charges),
- Among them, 98 industrial explosions, of which 80 were carried out within the territory of Russia (84 charges)

MAIN APPLICATIONS:

- Deep seismic sounding - 39
- Construction of underground storages - 25
- Stimulation of oil and gas production - 21
- Elimination of accidental gas gushers - 5
- Disposal of biologically hazardous effluents - 2
- Ore crushing - 2
- Construction of water storage reservoir - 1
- Canal construction - 1

- On August 12, 1953, the first in the USSR thermonuclear charge (RDS-6s) was successfully tested at the Semipalatinsk Test Site; its yield was 400 kt.
- In 1962, a thermonuclear module without fissile material was tested in VNIIEF, i.e. the first in the USSR thermonuclear ignition.

- In 1963, a radically new SINUS module had been developed by VNIITF, which was then successfully tested in 1965.

- In 1963, a clean thermonuclear unit design using gaseous fusion fuel was proposed by VNIITF.

- In 1965, this system was successfully tested in a physical experiment.

- In 1966, a test was conducted, where a practical groundwork was laid for obtaining unlimited power with fission-fragment activity provided only by a primer charge (the "Kaskad" system).

- In 1971-1972, VNIIEF developed an intermediate unit required for the operation of VNIITF’s “clean” unit which produced minimum tritium amount.
- According to the proposal made by E.I. Zababakhin at the scientific and technical council of the Ministry of Medium Machine-Building Industry on June 23, 1971, a decision was made on co-development through the joint efforts of the two institutes.
- In 1972, a successful testing of highly clean commercial charge with subsequent reduction of fission-fragment activity by more than 10 times was carried out through the joint efforts of the two nuclear research institutes.

General view of explosion crater in well 1004 (Chagan)

Crater lake Telkem-2 in 2002

Island in the center of “Taiga” object water basin

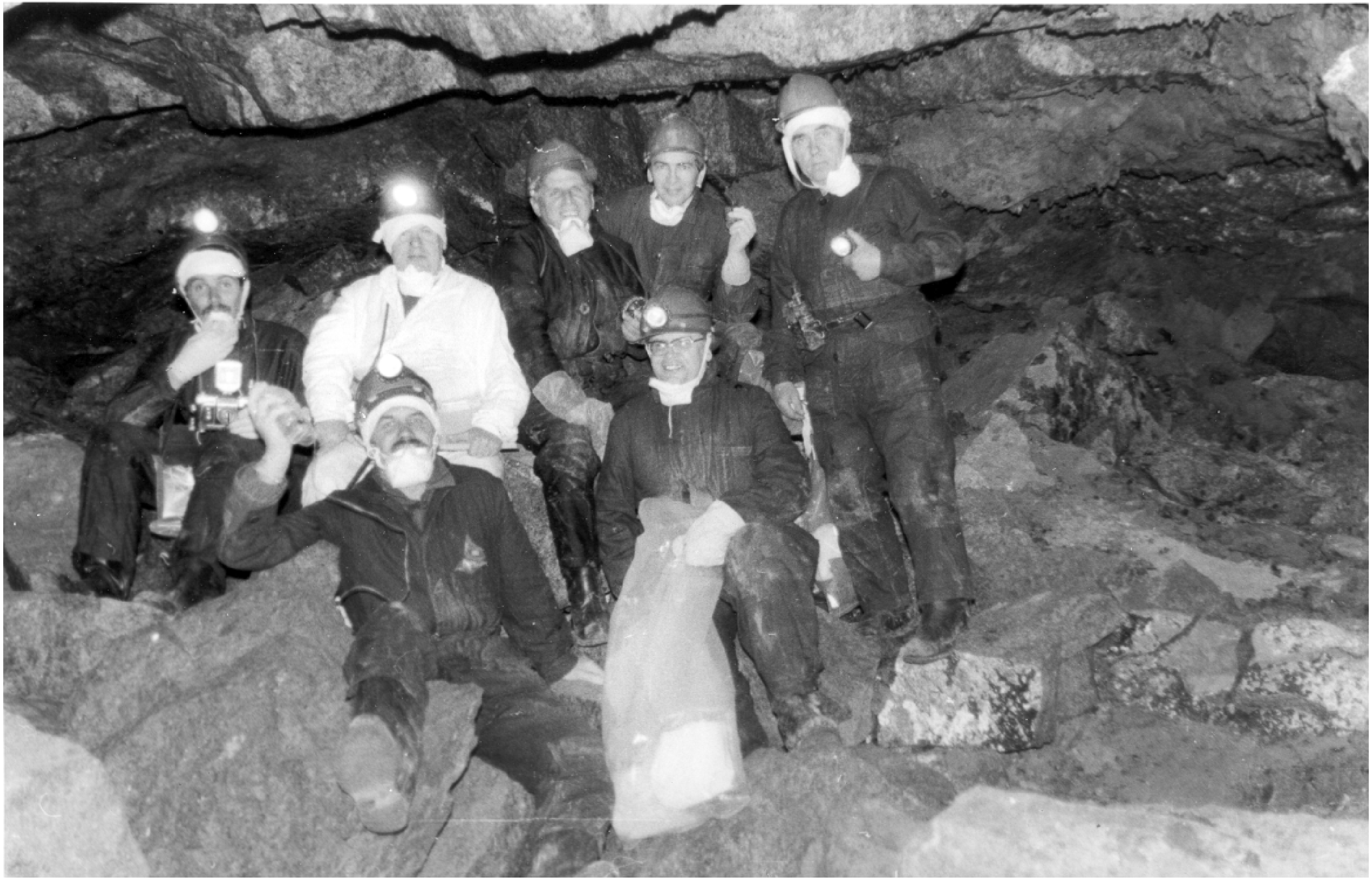
APPLICATION OF CLEAN CHARGES, ORE CRUSHING

- - As per seismic safety requirements, nuclear explosions with yields of 1-3 kt may be used for ore cruching;
- - the amount of ore broken by the explosion per unit of charge increases up to 10 times in the presence of a vertical slot raise and an undercut level;
- - mining cost of ore production can be reduced by 1.5-2 times.

Initiators and participants of "Dnepr-2" experiment

- Disposal of remaining fissile material and fission fragments, with the disposal cell located outside the fracture zone.
- September 4, 1972. ”Dnepr-1”. E=2.1 kt.
- Fractured rock volume of 121 th.m^3.
- More than 85 % of radionuclides were buried in the disposal cell.
- August 27, 1984. “Dnepr-2”: 2 charges with E=1.7 kt.
- Fractured rock volume of 488 th.m^3
- Potential for increasing up to 1450 th.m^3 per explosion.
- More than 94 % of radionuclides were buried in the disposal cell.

In disposal cell of “Dnepr-2” object



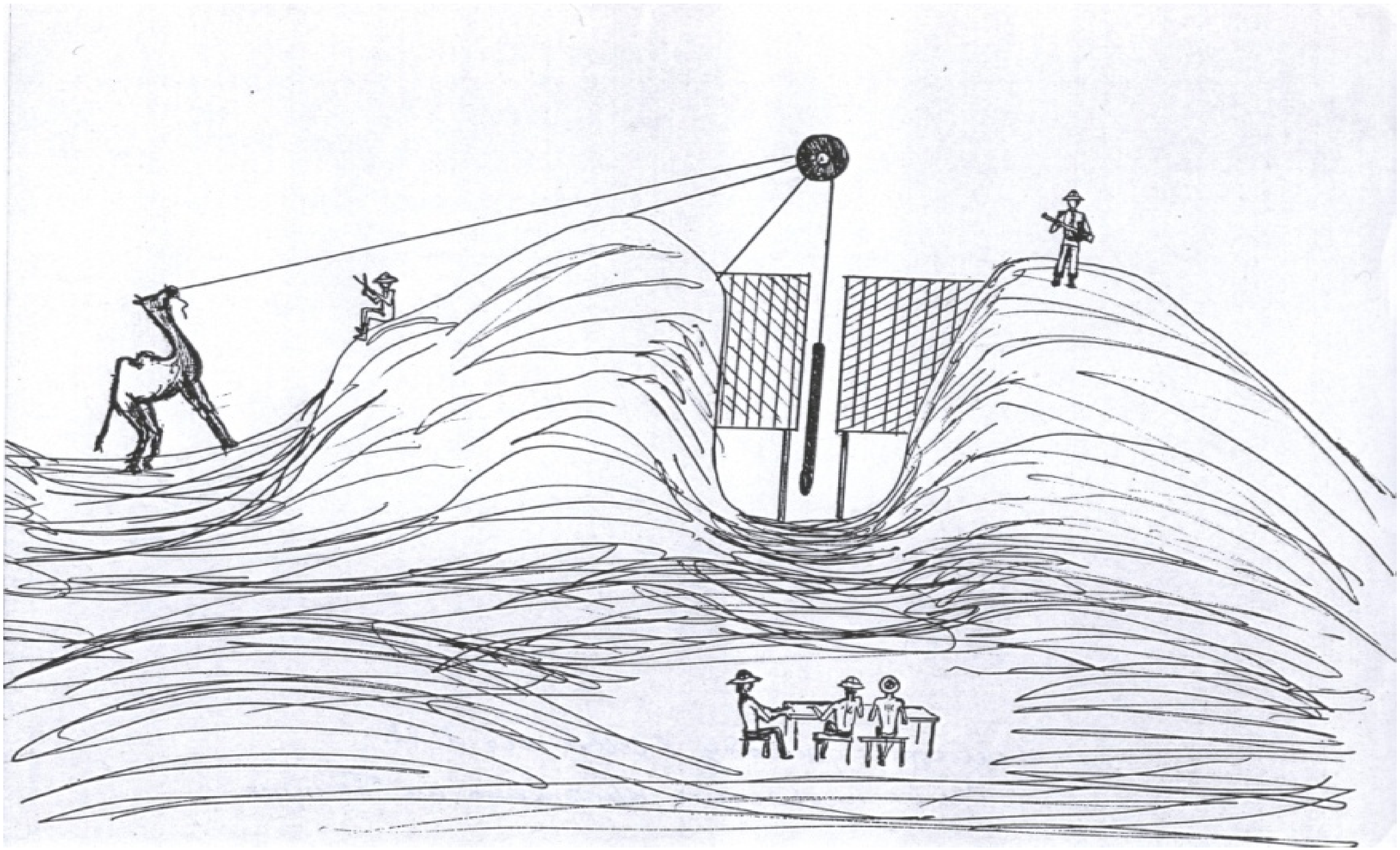
CHARGES FOR CONFINED EXPLOSIONS AND THEIR APPLICATION

- A heatproof charge of a 250 mm caliber capable of withstanding temperatures up to 110 ºC and pressure of 400 atm had to be prepared to extinguish a fountain at the Pamuk gasfield.
- E.P. Slavskiy assigned the development of such charge to VNIITF.

- A special automated system of control and detonation was developed for this charge.
- Due to the great depth of placement and a high temperature, difficulties occurred with the operation of detonation equipment and measurement techniques, but eventually they were overcome.
- In this experiment, the explosion yield was intended to be measured in the well with respect to shock wave velocity.

- The primary unit consisted of two main parts which in initial state were spaced so as to ensure a high degree of system subcriticality.
- According to the calculations, the selected initial spacing, L_0, ensured subcriticality even when surrounding the unit with reflectors. Transition to criticality occurred at a certain distance, L_{cr}, between the centers of the two parts. This distance was strongly dependent of the charge surrounding. The calculation and measurement results were not always in agreement.

Layout of critical mass measurements using Pamuk well mockup



SELECTION OF OPTIMAL CALIBER

- E.I. Zababakhin was the first to state the problem.
- The costs of deep wells increase rapidly with the caliber of a charge. As for the charge itself, the opposite is true: it becomes cheaper.
- Thus, the total cost of the charge and the well must have the minimum value dependent on the depth of the placement and the type of the charge.

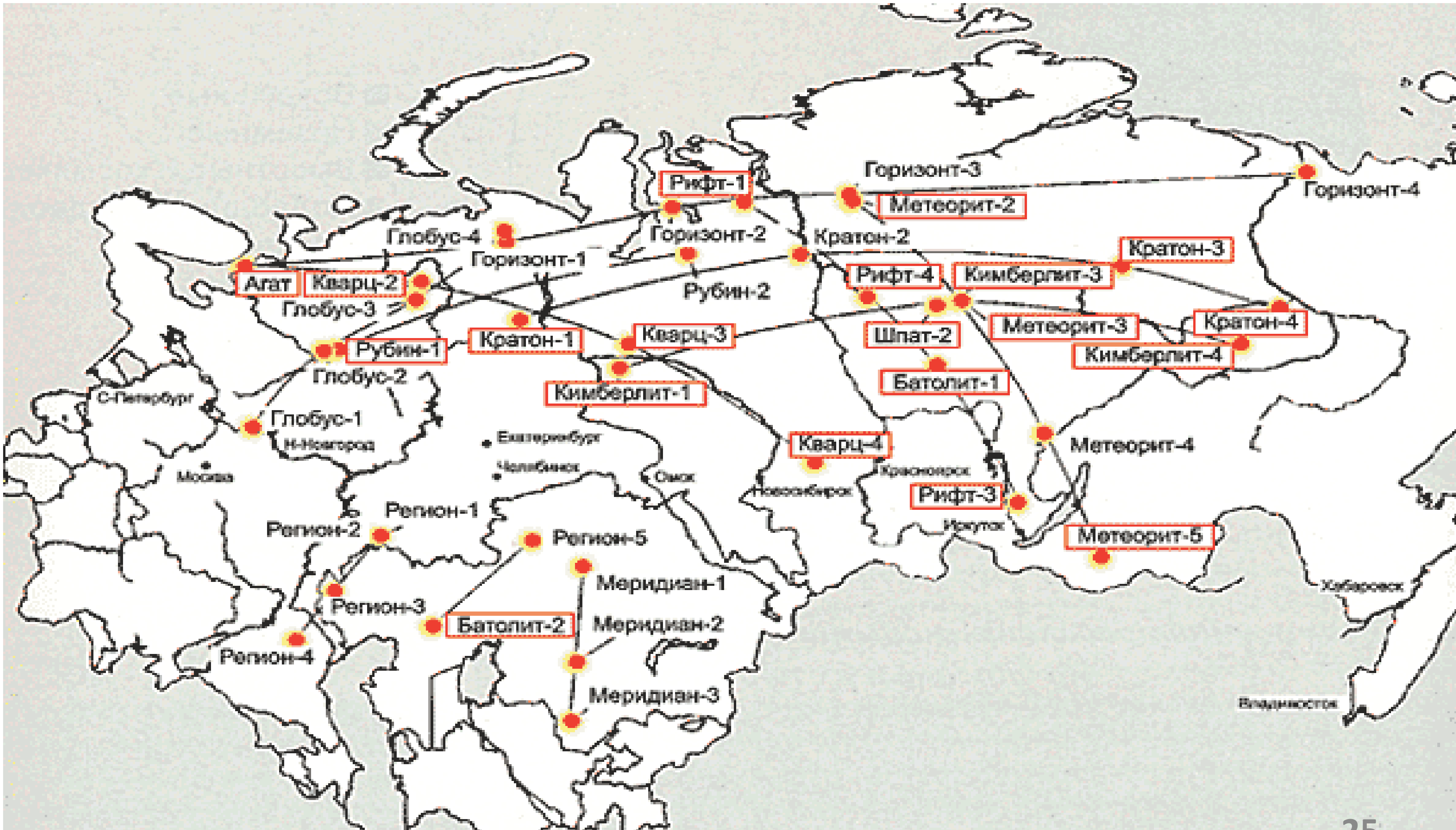
- In general, the unit came out to be good, and its fate was rather successful:
- 55 explosions were conducted with the view of the practical works for the purposes of the national economy,
- among them: seismic sounding – 21, cavities in rock salt – 22, stimulation – 12.

The concept of a “clean” charge is different for cratering explosions and confined explosions. Oil and gas do not capture Cs and Sr, but tritium penetrates into hydrocarbon molecules. It was necessary to reduce the amount of residual tritium as much as possible. A modified charge was developed and tested, with 0.1 g of residual tritium regardless of the charge yield. This allows to burn safely in a kitchen the gas that was used for pressurization of the cavity created in salt.

In VNIITF museum, near the nuclear explosion unit for confined explosions.

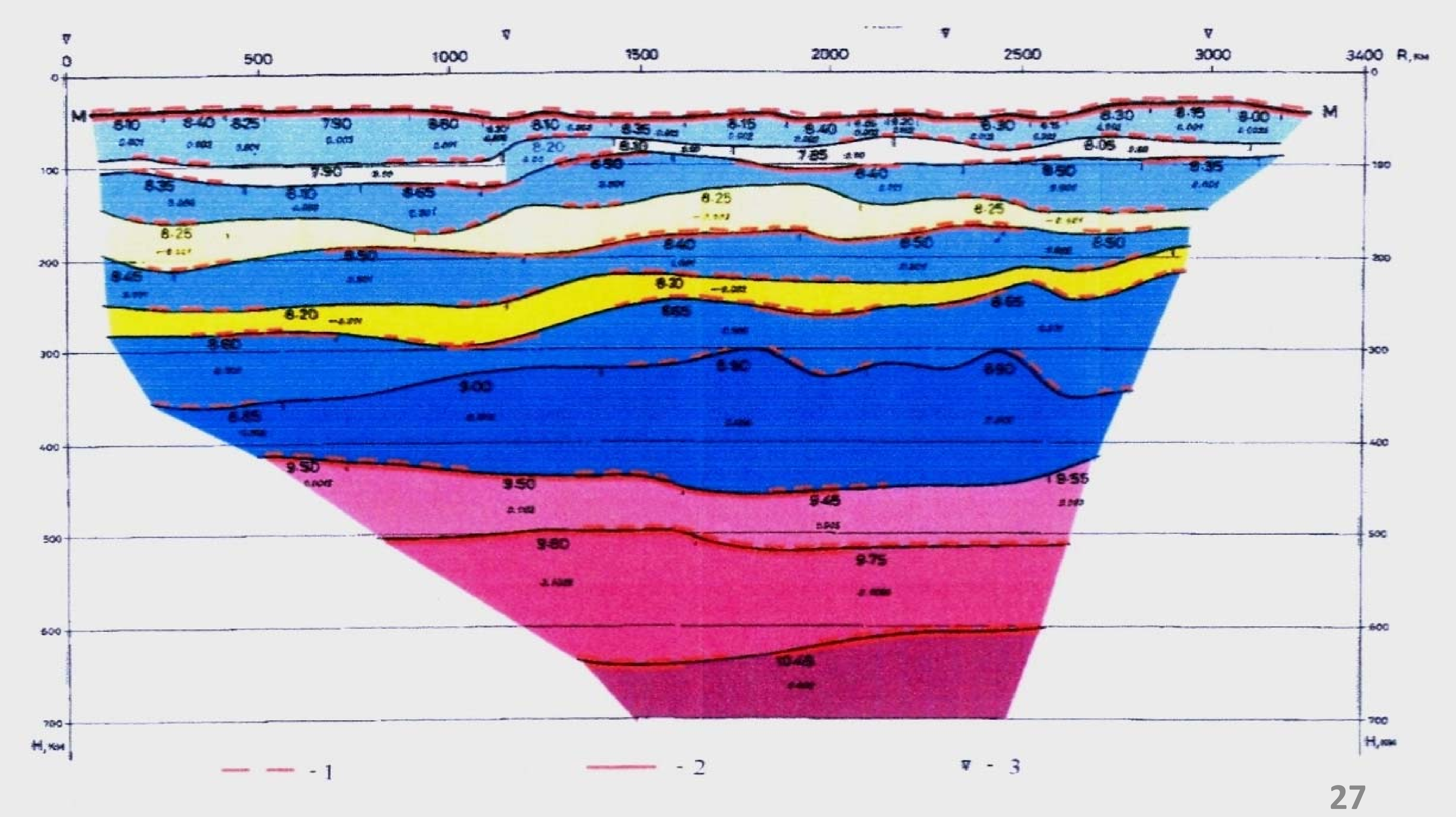
V. Vernikovsky, I. Shubina, guests from Los Alamos - N. Pruvost, D. Stillman, T. McLaughlin, and A. Vasiliev

Regional seismic profile network in the USSR



- In the period between 1971 and 1988, 39 underground nuclear explosions were carried out for seismic sounding of the crust at regional profiles extended for more than 70 th.km. In total, the USSR's deep seismic sounding studies, including special and ancillary nuclear explosions, were performed at the profiles extended for more than 100 th.km.
- One of the main requirements was to eliminate a possibility of radioactivity release to surface.

Upper mantle structure along the Kraton deep seismic sounding profile up to a depth of 700 km (1 – reflected waves, 2 – refracted waves, 3 – locations of underground nuclear explosions)

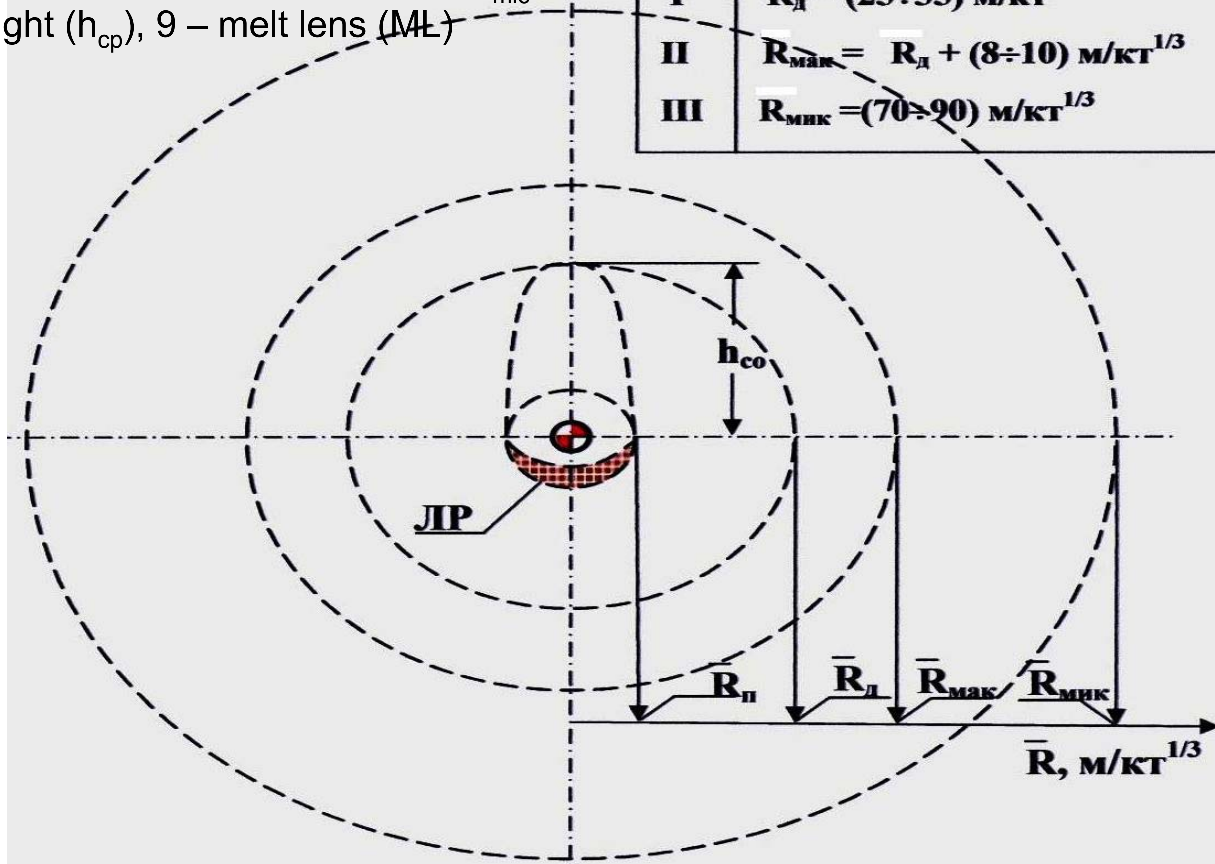


- The results of the studies showed that oil deposits extend beyond 4-5 km depths, as opposed to what had been assumed earlier.
- In the regions of Khanty-Mansiysk and Timan-Pechora province, prospective oil reservoirs were discovered at 5-7 km depths. And they are being developed already.
- A rich deposit - Markhinsk diamond field, was discovered in Yakutia; very important data on ore reserves in Norilsk was obtained.

- Transport of noble gas radionuclides to the surface was observed for 16 out of 39 deep seismic sounding explosions, i.e. insignificant gas leakage through the cable occurred.
- Accidental release of nuclear explosion products took place In three cases out of sixteen:
- at objects Globus-1 and Globus-3, pressure flow of radioactive noble gases mixed with daughter radionuclide aerosols, iodine and tellurium isotopes,
- at object Kraton-3, accidental release of non-separated mixture of radioactive explosion products.

1 - Zone No., 2 – External boundaries of mechanical alteration of rocks, 3 – m/kt, 4 – cavity radius (R_{cav}), 5 – crush zone radius (R_{cr}), 6 – macrofracture zone radius (R_{mac}), 7 – microfracture zone radius (R_{mic}), 8 - caved pillar height (h_{cp}), 9 – melt lens (ML)

№№ зон	Внешние границы зон механического преобразования пород
—	$\bar{R}_п$ = (6÷8) м/кт$^{1/3}$
I	$\bar{R}_д$ = (25÷35) м/кт$^{1/3}$
II	$\bar{R}_{мак}$ = $\bar{R}_д$ + (8÷10) м/кт$^{1/3}$
III	$\bar{R}_{мик}$ =(70÷90) м/кт$^{1/3}$

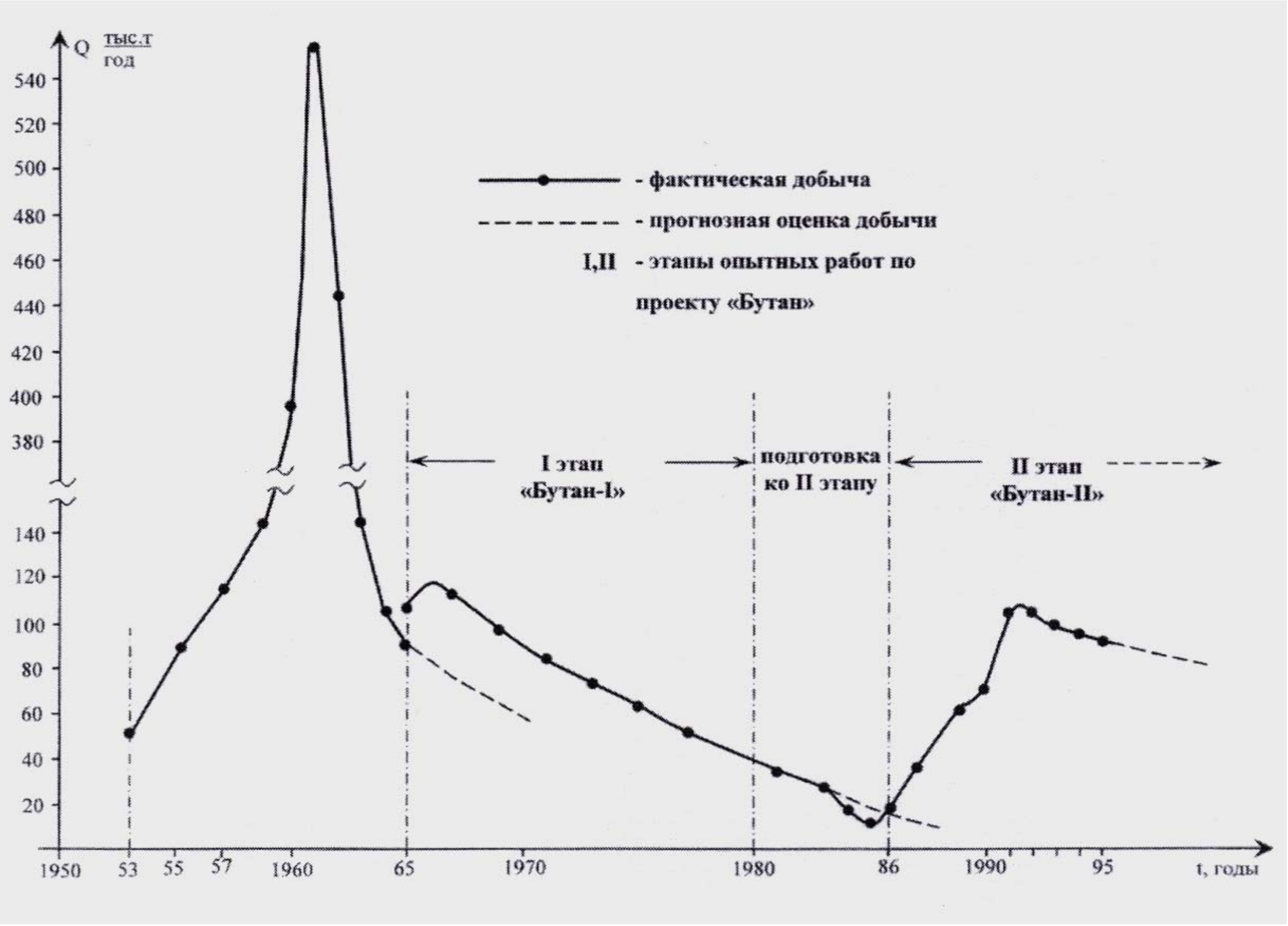


$R_п$ – радиус полости
$R_д$ – радиус зоны дробления
$R_{мак}$ – радиус зоны макротрещиноватости
$R_{мик}$ – радиус зоны микротрещиноватости
h_{co} – высота столба обрушения
ЛР – линза расплава

- Nuclear explosions were carried out according to the project, in two stages:
- The first stage – simultaneous (March 3,1965) firing of two charges, each of them having a yield of 2.3 kt, in wells No. 617 and No. 618 spaced ~200 m apart, and firing of the single charge (June 10,1965) with a yield of 7.6 kt in well No. 622 located at a distance of 300 m from well No.617;
- The second stage – firing of two charges (June 16 and 25, 1980) yielding 3.2 kt each, in wells No. 1 and No. 3 spaced 557 m apart.

Oil production at Grachevsky oil deposit

1 – th.t/year, 2 – actual production, 3 – predictive estimate of production, 4 – stages of experimental works as a part of the Butan project, 5 – stage I, Butan-I, 6 – preparations for stage II, 7 – stage II, Butan-II, 8 - years



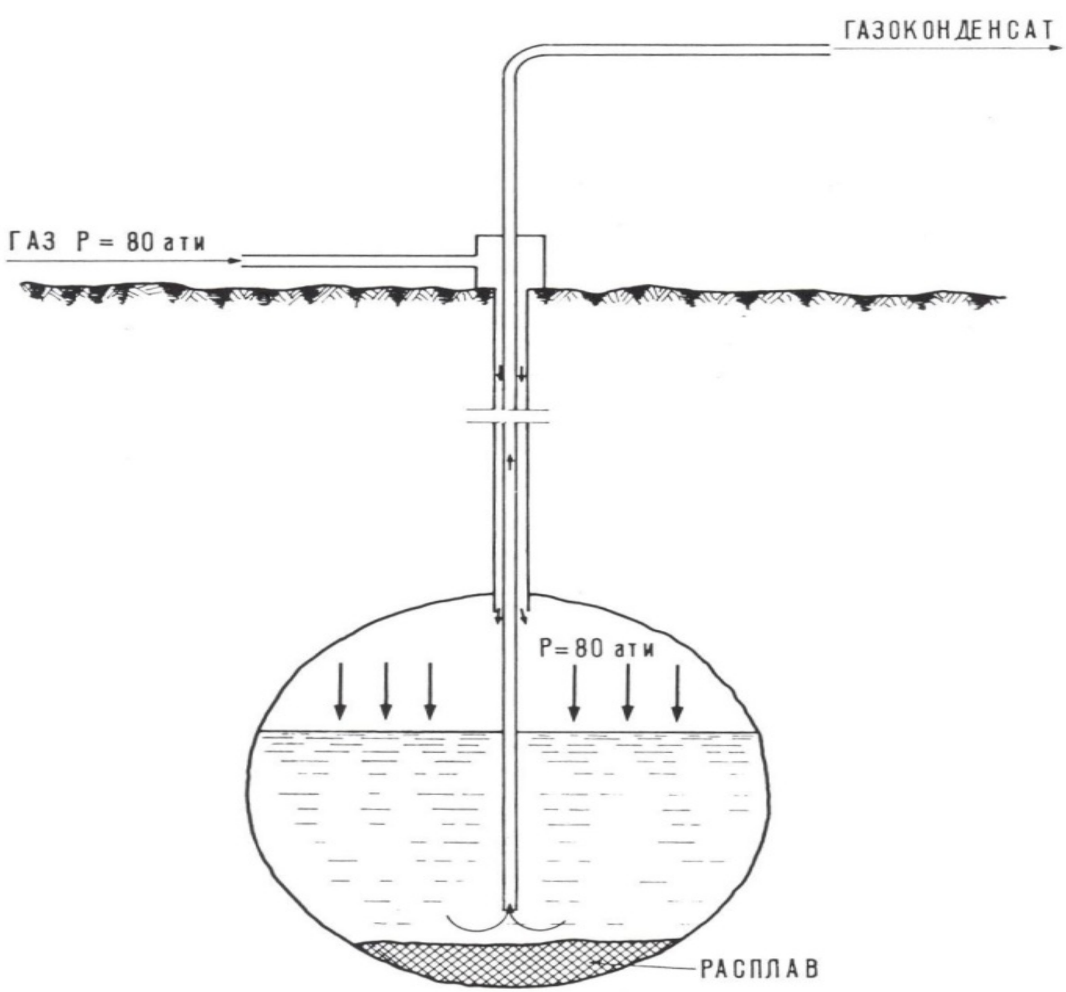
At objects Neva-1, Neva-2 and Neva-3, the flow rates of all explosion-stimulated wells increased greatly (> 20 times) and averaged Qfeq = Qoil + Qgas ≈ 70 t/day of fuel equivalent (1 t of oil ≈1000 m^3 of gas).

This flow rate included significant quantities of steady-state oil inflows (Qoil = 15-30 t/day) which were obtained at the deposit for the first time.

A principal possibility of using nuclear explosions for cost-effective and environmentally safe stimulation of oil and oil-gas fields with complex structure was proven.

The results of the works (at the Griffon object, in particular) have shown that the mistakes of the designers, which had not accounted for the peculiarities of this technology, can lead to complex environmental effects and reduction of economic benefits.

Scheme of gas condensate storage tank
1 – gas condensate, 2 – gas, P=80 atm, 3 - melt



- 24 underground tanks in rock salt were created at three large gas-condensate fields with a total initial volume of about 850 th.m^3.
- The first three gas-condensate storage tanks with a total volume 100 th.m^3 were developed at Orenburg gas-condensate field in 1970-1973.
- They successfully operated for 20 years, which made it possible to avoid losses of very high-value product in an amount of more than 2 mln. t.
- Before their construction, the associated gas condensate used to be burned.

General view of wellhead setup for tank usage

DISPOSAL OF BIOHAZARDOUS EFFLUENTS

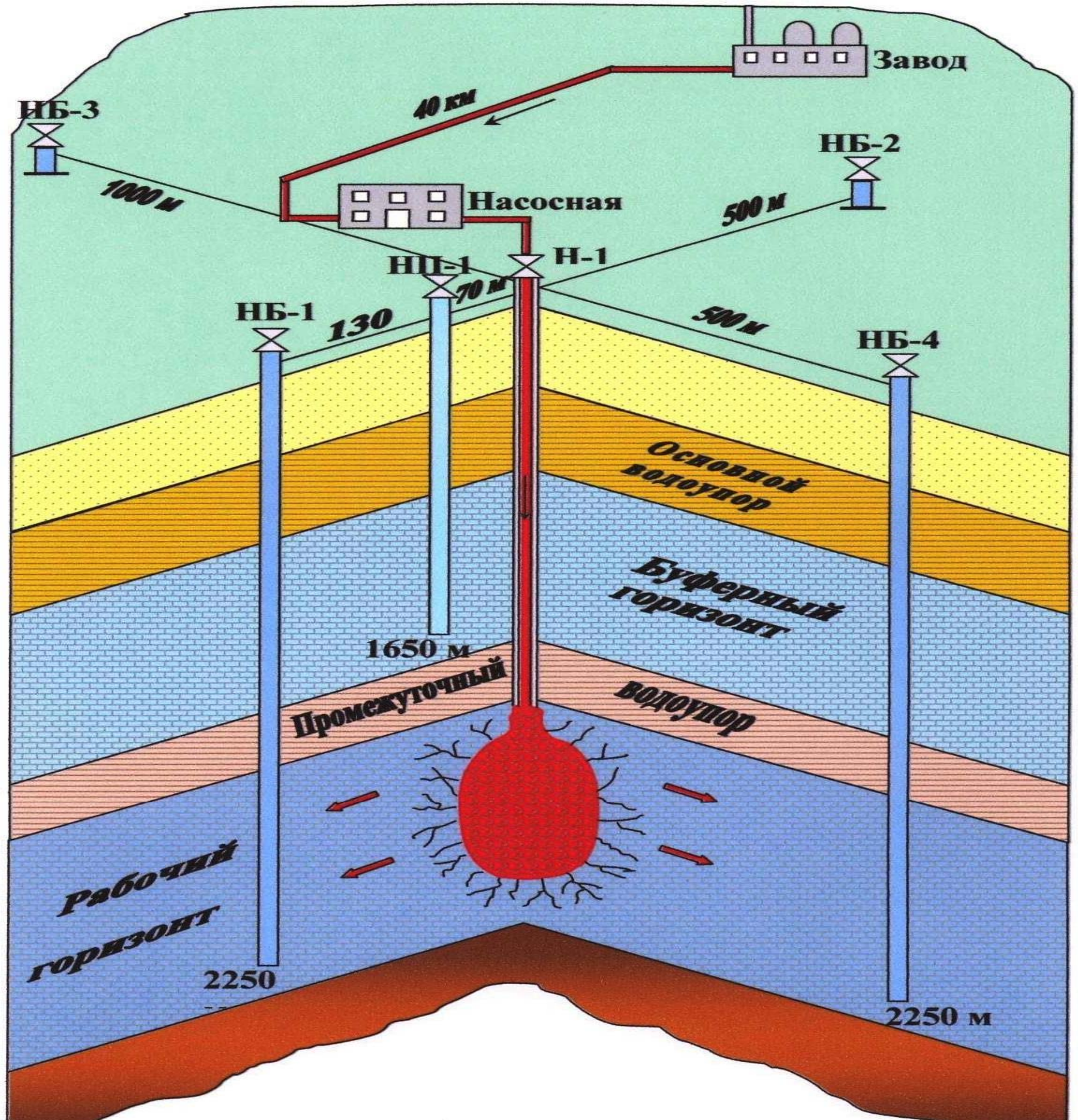
- The world practice has the experience of industrial effluent disposal in deep underground water-bearing horizons through the regular bore wells. These effluents are completely removed from the human habitat.
- The disadvantages of the industrial effluent disposal through the regular bore wells are as follows:

  - they have low average injectivity;

  - low probability of completion of the well areas with high natural injectivity;

  - low filter area and accumulating tank for suspended particles.
- Detonation of the nuclear charge with a yield of 10 kt was provided in well No. N-1 at a depth of 2026 m on the day of the 75th birth anniversary of Minister E.P. Slavskiy (October 26,1973).

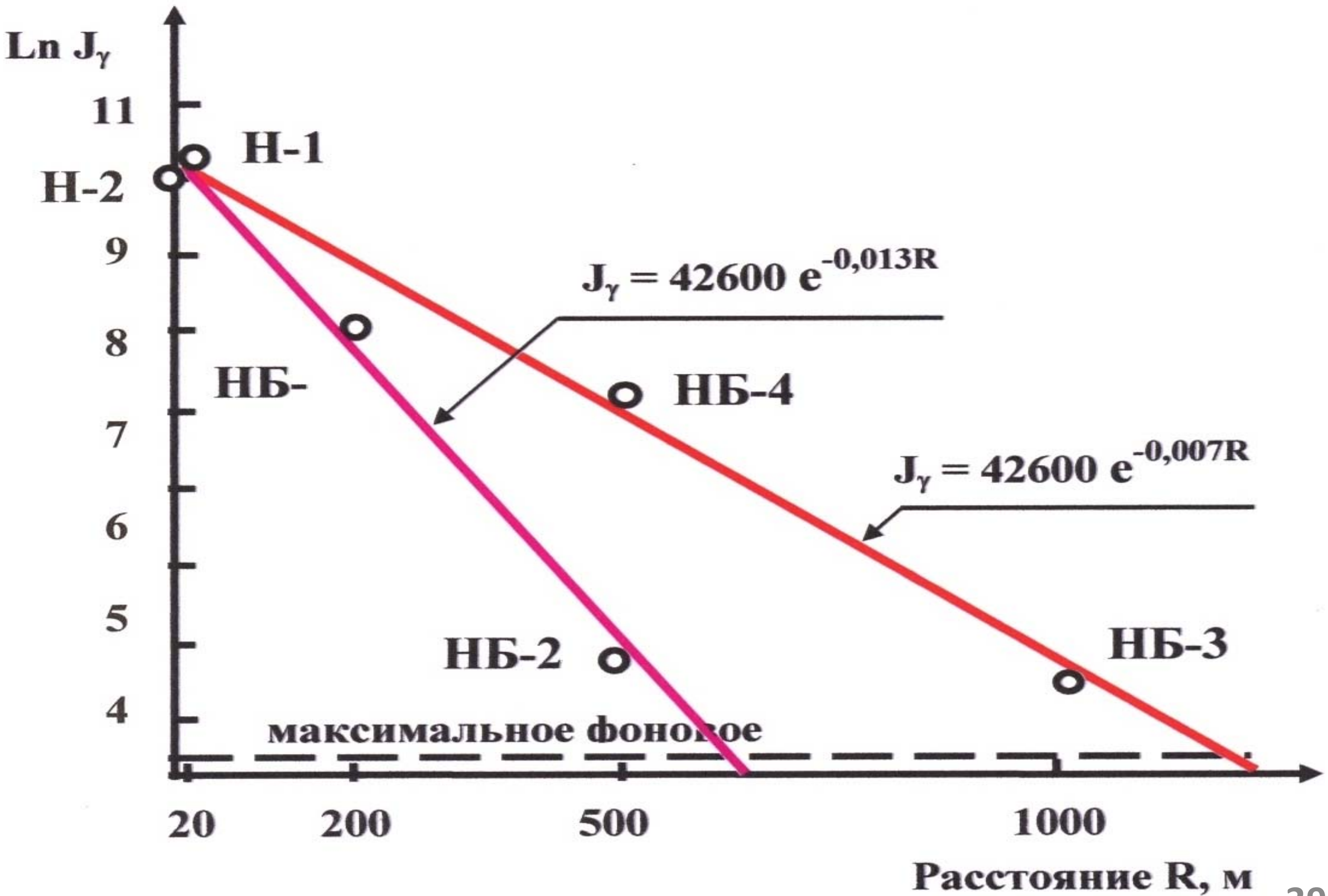
1 – plant, 2 – pump house, 3 – main confining bed, 4 – buffer horizon, 5 – intermediate confining bed, 6 – production horizon



Н-1 – нагнетательная скважина
НБ 1-4 – наблюдательные скважины
НП-1 – пьезометрическая скважина

N-1 - injection well
NB 1-4 – observation well
NP-1 - pressure-observation well

Change in maximum gamma dose rates at production horizon of Kama-2 object
1 – maximum background radiation, 2 – distance, R (m)



- By January 1, 2017, 45 mln. m^3 of industrial effluents has been pumped into Kama-2. More than 2100 tons of suspended particles, which accumulated within the caved pillar, were introduced to the bottom-hole zone. One enlarged well No. N-1 can replace at least 20 regular wells.
- After a reconstruction of the above-ground equipment in 2014, operation of Kama-2 was extended for another 10 years with the same flow rate of 4000 m^3/day.
- The total environmental damage prevented by the disposal of industrial effluents at both objects, as of January 1, 2014, was estimated about 241 mln. rubles (at 1984 values).

- Kama-2 object can be regarded as a full-scale model for the investigation of radionuclide migration, their washing from a melt lens or from an demaged underground radioactive waste storage.
- It was estimated that one year of industrial effluent pumping through the explosion zone at a rate of 4000 m^3/day is equal to approximately 1000 years of carryover of radioactive substances from the explosion zone with filtering of the underground waters through this zone at a natural rate.

- As with any new business, we had our failures as well.
- For some of the proposed technologies, nuclear explosions did not have the expected effect.
- For some others, a more detailed geological formation was needed on the environments, in which the explosion was carried out.
- There were some failures, although occasionally, due to the technological violations when performing well drilling and filling or well penetration after the explosion.
- These failures prove that the development of complex technologies has to be accompanied with the growth of implementers' culture.
- All participants must meet the requirements of nuclear culture standards.
- Unfortunately, not all of them were prepared for it.

- Underground nuclear explosion objects are the locations of special radioactive waste disposal, which have to be transformed to preservation locations and then to the locations of ultimate isolation of special radioactive wastes.
- The important problem is the long-term behavior of radionuclides over a period of hundreds and thousands of years and their possible migration.
- The projects focused on their reliable isolation should be developed and implemented in a fairly open manner, with public and ecological organizations participating in the discussions, as it is now performed by the National operator together with the Public Council of the Rosatom.

Thank you for your attention!