NUCLEAR EXPLOSIONS IN THE USSR:

THE NORTH TEST SITE

REFERENCE MATERIAL

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FOREWORD

During the last decade a number of publications have been issued containing information about the past nuclear weapons tests and their radiological consequences for the environment and the public. In Russia, monographs devoted to operation of the Semipalatinsk Test Site, Kazakhstan, and the North Test Site, located on the Novaya Zemlya archipelago in the Arctic Ocean, were recently published as well as a monograph devoted to the peaceful underground nuclear explosions.

This document contains reference materials and papers of Russian experts presented at international and national scientific meetings and public hearings devoted to operation of the North Test Site and the radiological impact of nuclear weapons testing. These materials were originally published in Russia in 1993 and the second edition in 1999 as "Nuclear Explosions in the USSR: The North Test Site, Reference material on nuclear explosions, radiology, radiation safety". The monograph was published by the Interagency Expert Commission on assessment of radiation and seismic safety of underground nuclear tests, Scientific-Industrial Association"V.G. Khlopin Radium Institute", Russian Nuclear Society (Section: Environmental aspects of nuclear power), and the Centre for Public Information on Nuclear Power.

The second, corrected and extended edition, edited by Academician V. N. Mikhailov, Dr. Yu. V. Dubasov and Prof. A. M. Matushchenko is the first issue containing detailed reference materials on nuclear explosions for the period 1955–1990 at the North Test Site, and on the radiation situation on its territory and in adjacent regions.

The document contains contributions from experts from the Ministry of Atomic Energy, the Ministry of Defence, the Ministry of Environment, and the Ministry of Health of Russia: K. N. Andrianov, V. N. Bazhenov, V. V. Vyskrebentsev, Ya. Ye. Doskoch, Yu. V. Dubasov, V. P. Dumik, G. Ye. Zolotukhin, V. M. Ivanov, V. M. Karimov, V. V. Kasatkin, G. A. Kaurov, Ye. P. Kozlov, G. A. Krasilov, A. S. Krivokhatskiy, G. G. Kudryavtsev, V. I. Kulikov, A. L. Mal`tsev, A. M. Matushchenko, V. N. Mikhailov, K. V. Myasnikov, A. V. Pichugin, P. V. Ramzaev, V. G. Safronov, V. G. Strukov, V. I. Filippovskiy, N. P. Filonov, K. V. Kharitonov, G. A. Tsyrkov, A. K. Chernyshov, V. V. Chugunov, Yu. Ye. Shipko under the leadership of V. N. Mikhailov, G. Ye. Zolotukhin and A. M. Matushchenko.

The data were checked by the Interagency Expert Commission on assessment of radiation and seismic safety of underground nuclear tests within the complex programme of radiological investigations of the North Test Site and adjacent territories REGION-2. The reference material has been reviewed by members of the National Commission for Radiation Protection of the USSR: G. M. Avetisov, K. I. Gordeev, and U. Ya. Margulis.

At the request of the editors of the Russian version, the document, which contains much information previously unknown to the world's radiological protection community, was translated into English by the International Atomic Energy Agency (IAEA) and posted on the website of its Department of Nuclear Safety and Security. The English translation contains all the technical data and technical papers found in the Russian version but some papers of a memorial nature are omitted.

The IAEA officer responsible for this publication was M. Balonov of the Division of Radiation and Waste Safety.

CONTENTS

1. INTRODUCTION

The main political goal of Russian military doctrine today is to eliminate war, and to strengthen international stability and safety. The world is changing rapidly. Large-scale actions taken by our country and by the USA in reducing nuclear arsenals are striking examples of these changes.

The only alternative to nuclear equilibrium, to the strategy of containment, is the regime of total trust and openness, and universal and complete destruction of nuclear weapons and a ban on their development. This is our goal. Nuclear weapon tests play a special role in this endeavour.

By the end of 1991, 2053 nuclear tests had been recorded. They were carried out by five States: the USA (since 1945), the USSR (since 1949), the UK (since 1952), France (since 1960) and China (since 1964). During these tests, the design of nuclear weapons was developed, the phenomena accompanying explosions were studied, the effect on weapons, military equipment, various installations and the environment was examined, and means and methods of nuclear defence and detection were also tested. In addition, locations and techniques for concealing nuclear tests were investigated.

Along with this, since the appearance of nuclear weapons, the Soviet Union (and then Russia) has been fighting for their complete banning, starting with a proposal to the United Nations in 1946.

In Moscow in 1963, the USSR, the USA and the UK signed a Nuclear Test Ban Treaty forbidding explosions in three media: in the atmosphere, in space and under water. Currently, this Treaty has been ratified by 117 countries, 104 of which have also signed the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT). By the end of 1991, the NPT had been signed by 143 countries. After the conclusion of the 1963 Moscow Treaty,, our country has persistently fought for a total ban on nuclear tests. These efforts resulted in the signing of a treaty between the USSR and the USA in Moscow on 3 July 1974 on limiting the yield of underground nuclear weapons tests to 150 kt of TNT equivalent. From April 1976, the Soviet Union (and then Russia) has been adhering to the treaty's provisions. The treaty and the protocol to it signed in Washington on 1 June 90 were finally ratified by the USSR and the USA at the end of 1990.

According to the Treaty, in addition to using the national means of verification, the monitoring party has the right to use the hydrodynamic method to measure an explosion yield greater than 50 kt, and to carry out on-site inspection for explosions with a yield greater than 35 kt. as the monitoring party also has the right, for the purpose of monitoring, to use three seismic stations located on the territory of the side conducting the tests. In order to strengthen credibility and to improve national technical means of verification, the parties have the right during each of the first five years to take measurements of the blast yield of the other party by the hydrodynamic method, even if there are no tests with a planned yield above 50 kt. The protocol, developed as a result of bilateral negotiations in Geneva in only three years, provides for unprecedented technical verification measures. However, in this connection it should be noted that the initial Protocol of the 'Threshold" Treaty included only national technical monitoring means and, therefore, it was open for signing by other countries. On the other hand, the new Protocol of 1990 anticipates application of the hydrodynamic method for on-site monitoring of the test yield. Including this method was the USA's prerequisite for signing, and this actually doomed the Protocol to be bilateral only. Russia is concerned because of continuing nuclear tests in other countries. Nevertheless, due to the efforts of the USSR and the USA, a big step was taken towards limiting nuclear tests. The main result of these negotiations was openness of professional discussion of many scientific problems and mutual understanding of complexity of scientific and technical aspects of controlling limitations of nuclear tests.

The main basis for success of the Geneva talks was the Joint Verification Experiment (JVE), during which nuclear explosions with yields of 100–150 kt were conducted at the Nevada test site (17 August 1988) and the Semipalatinsk test site (14 September 1988). For the first time in the history of underground tests, many versions of explosion yield verification methods were jointly tested, including — and this is most important — the non-intrusive hydrodynamic method which eliminates the need for obtaining data on the nuclear weapon design during the verification process. Joint development of non-intrusive devices and monitoring equipment control systems which has already been completed is a striking example of the contribution by scientists from the two countries to limiting nuclear tests. One of the main outcomes of the JVE was direct mutual calibration of national seismic means of verification of nuclear tests. During the experiment, the parties exchanged complete data on five nuclear explosions. At both the Nevada and Kazakhstan sites, Soviet experts obtained complete and unrestricted explosion data. At a meeting with American experts after the JVE, a Soviet delegate noted: "Let us hope that the high level of diagnostic equipment and professional skills of Soviet experts in this unique experiment have demonstrated to the American scientists that we should compete not in developing "third generation" weapons, but in creating conditions for mutual understanding and trust. These two explosions served as a ray of hope for a non-nuclear world."

Now all prerequisites exist for developing the success achieved so far in limiting the number of tests performed annually. Quantitative limitation of tests will be a qualitatively new step that requires a precise definition of a "nuclear explosion" for this kind of weapon. The mechanism for monitoring the number of nuclear tests can be established on a broad international basis by including national monitoring means in an international network and on-site inspections.

Today, cessation of all nuclear tests is of fundamental importance for preventing the development of third generation nuclear weapons, and ensuring that it never leaves the stage of exploratory research to reach the stage of full-scale development. Third generation weapons are weapons with new properties with regard to efficiency and reliability as well as global consequences. On the one hand, they may result in global radioactive contamination hundreds and thousands of times smaller than existing weapons but, on the other, they are capable of hitting strategic targets both in space and on Earth. This particular fact causes alarm since in it may lead to a temptation to use them in any local conflict. To prevent the development of such weapons is an important task facing all humankind.

The USSR conducted only one underground nuclear test in 1990 North Test Site, 24October 90), and none since 1991. Since 29 August 1991, the President of Kazakhstan has completely closed the Semipalatinsk test site for nuclear tests, and since 26 October 1991, the President of the Russian Federation has introduced the next unilateral moratorium on nuclear tests at the North Test Site for one year. It is obvious that the moratorium will be prolonged. It should be noted that the prospects of nuclear tests at the North Test Site cause serious concern to the people of the Russian northern regions and of the Scandinavian countries. At the same time, comprehensive radiological surveys of the test site territory and of the adjacent regions conducted since 1991 within the framework Complex programme "Region-2" by experts from the State Committee for Hydrometeorology, the Ministry of Public Health, the Ministry of Atomic Energy, and the Ministry of Defence of Russia demonstrate that parameters of the radiation situation on the Novaya Zemlya Archipelago are presently within the limits typical for the entire territory of the country, and are determined by the existing background of global contamination from earlier nuclear tests conducted both in our country and abroad.

Basically, the radiation background on the test site territory does not differ, within the limits of fluctuations, from the natural background radiation in the territories adjacent to the test site, excluding the background of local sanitary-protection zones, in which atmospheric nuclear tests had been conducted before 1963. It is important to note that given a sufficient nuclear device depth, high-quality stemming of a nuclear device in the ground, adherence to established organizational and engineering safety measures, and appropriate weather conditions at the explosion moment and two–three days later, the ecological damage at test site and in the adjacent territories can be reduced to a minimum.

From the very beginning of underground nuclear tests, adequate measures were taken to prevent release of radioactive products to the surface. Meanwhile, the technology for retention of radioactive products underground improved as new experimental data became available and knowledge expanded. Radiation safety of underground nuclear tests is now ensured by a range of equipment and facilities and organizational measures for the prevention of accidents or limitation of their consequences. Moreover, radiation safety measures ensure that the population is not exposed to radiation doses above international standards in all situations. Procedures for international or bilateral monitoring of underground nuclear test safety urgently need to be developed. In this regard, the necessary data for signing an agreement or a treaty on the verification criteria and procedures both at the nuclear test site and beyond its boundaries are available.

During the past six years, Russia prolonged its moratorium on nuclear tests, as did the USA and France. Just before signing the Comprehensive Test Ban Treaty (CTBT), France decided to conduct a series of tests in 1995–1996 on the Mururoa atoll, which was completed in January 1996 by the sixth test. The People's Republic of China carried out five nuclear tests during this period. In May 1998, India and Pakistan conducted a series of underground nuclear tests.

During the same period, the North Test Site received, in accordance with the Decree of the President of the Russian Federation of 27 February 1993 No. 194, the *status* of Central Test Site of the Russian Federation. Nevertheless, not a single test was performed just before signing the CTBT. On 24 September 1996, at the United Nations Headquarters in New York, the Treaty was signed by all nuclear weapon States, and now about 140 States are signatories.

These reference data are one of the elements of the effort being presented for the purpose of clarifying radiological and environmental assessments made by experts from various organizations in the framework of the special comprehensive programme of research of the radiation and public health environmental situation at the North Test Site and in adjacent regions.

Academician V. Mikhailov

Chief Editor

2. NORTH TEST SITE: BASIC INFORMATION ON NUCLEAR TESTS (1955-1992)

K.N. Andrianov, V.V. Vyskrebentsev, Yu.V. Dubasov, V.P. Dumik, G.Ye. Zolotukhin, V.M. Ivanov, V.M. Karimov, G.A. Kaurov, G.A. Krasilov, Ye.P. Kozlov, G.G. Kudryavtsev, V.I. Kulikov, A.M. Matushchenko, V.N. Mikhaylov, P.V. Ramzayev, V.G. Safronov, V.G. Strukov, V.I. Filippovskiy, K.V. Kharitonov, G.A. Tsyrkov, A.K. Chernyshev, V.V. Chugunov

2.1. NUMBER OF NUCLEAR TESTS

The tests were performed at three technological sites:

Chernaya Bay (zone A – a series of atmospheric nuclear explosions (bursts), three underwater nuclear explosions and five underground nuclear tests (NTs) in boreholes); Matochkin Shar Strait (zone B – 34 underground NTs in tunnels); south end of the Severny Island between Mityushikha Bay and Sulmeneva Bay, Sukhoy Nos Peninsula (zone C – series of aerial NEs). Figure 1 shows the location of the test sites.

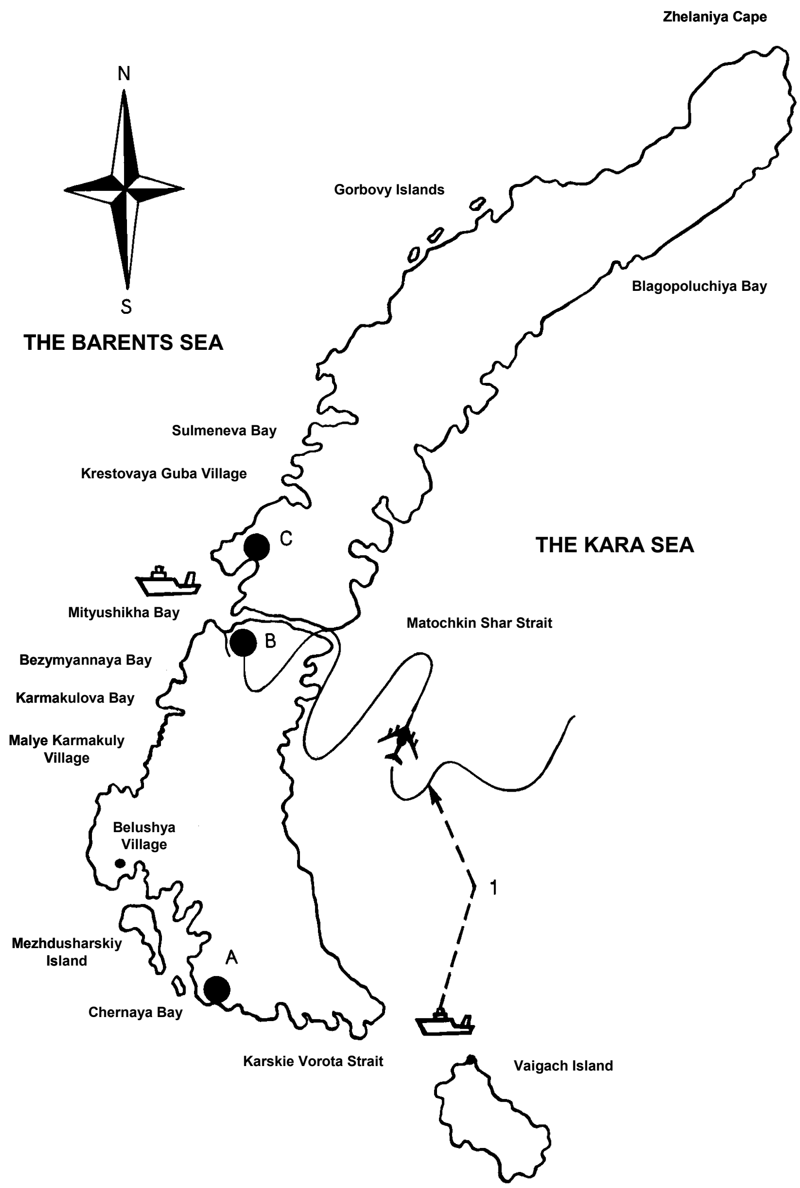


FIG. 1. The North Test Site.

A – the zone for underwater and on-water nuclear tests (1955–1962), an surface nuclear explosion (7 September 1959) and five underground nuclear tests in six vertical boreholes (shafts) (1972–1975);

B – the zone for 34 underground nuclear tests in horizontal tunnels (1964–1990);

C – the zone for aerial nuclear tests (1957–1962).

In all, 130 NTs were performed from 21.09.55 till 24.10.90, including:

88 atmospheric nuclear tests (one surface test –7 September 1957, 85 aerial ones, which were performed at the altitudes of 0.7–10 km depending on the yield, i.e. on the "bombing" mode, whereby the expanding fireball did not touch the earth`s surface and caused no local contamination on the test site, but contributed, along with nuclear tests of other countries, to the total global contamination of the environment; two on-water tests: 16 kt – 27 October 1961 and 6 kt – 22 August 1962); three underwater nuclear explosions (3.5 kt – 21 September 55, 10 kt – 10 October 1957 and 4.8 kt – 23 October 1961); 39 underground nuclear tests (their chronicle is presented in Fig. 9, Section 4).

The first nuclear explosion at the test site was detonated underwater on 21 September 1955 (by that time the USA had set off two nuclear explosions of this type– 24 July 1946 and 14 May 1955).

A super high-yield hydrogen bomb with a TNT equivalent of about 50 Mt was tested on 30 October 1961, above the Novaya Zemlya archipelago (zone C), at an altitude of about 3.5 km. It is important to note that the energy release due to the fission reaction in this ` test was less than 10%. Note also that the USA by this time had performed four nuclear tests of the megaton category in the atmosphere (10–15 Mt each) at the Enewetak and Bikini atolls (28 February 1954, 26 March 1954, 4 May 1954, 31 October 1954). These were ground surface tests, which drew enormous amounts of soil particles in the fireball, and water surface ones, which undoubtedly led to considerable radioactive contamination of adjacent territories (e.g. during the "Mike" nuclear test, a 50 m deep crater with a diameter of approximately 1.5 km was formed).

At the North Test Site, the last burst in the atmosphere was performed on 25 December 1962, and underground on 24 October 1990

Information

(a) *As of 1 January 1997, 2049 tests have been recorded, including:*

USA – 1032, of which 212 were in the atmosphere before 1963 (nine high-altitude, 83 aerial, 84 ground surface, and 36 water surface), five were underwater and 815 were underground (of which 771 were after signing the Moscow treaty of 1963). About 268 nuclear tests were not announced.

USSR – 715, of which 216 were in the atmosphere prior to 1963 (five high-altitude, 177 aerial, including the aerial nuclear explosion on 14 September 1954, in the Orenburg region during army field exercises with live nuclear weapons, 32 ground surface and two water surface), three were underwater and 496 were underground tests (including 340 at the Semipalatinsk and 39 at the North Test Sites, and 117 in other regions of the country for industrial purposes after signing the 1963 Moscow treaty).

FRANCE – 210, of which 50 were in the atmosphere prior to 1975 (four surface in the Sahara desert and 41 aerial tests at the Pacific test site).

UK – 22 in the atmosphere prior to 1959 (eight aerial, five ground surface and one -water surface at the test site in Australia, eight aerial ones at Christmas Island, and 23 underground tests jointly with the USA at the Nevada test site).

CHINA – 47, of which 22 were in the atmosphere prior to 1981 (16 aerial, six surface tests) and 25 underground tests (at the Lobnor test site).

(b) *Characteristic issues in the conduct of nuclear explosions:*

The USA was the first to carry out a nuclear test explosion (16 July 1945, Trinity) which was conducted near the village of Alamogordo, New Mexico. Then, a large series of nuclear tests was performed at the Pacific test site – on the islands/atolls of Christmas, Johnston, Bikini and Enewetak. The USA also performed separate tests in the Pacific ocean, in the south Atlantic, at Amchitka (Aleut islands) and on the continent – near the villages of Carlsbad and Farmington, New Mexico, at Hattisberg, Mississippi, at Rifle, Colorado, and at the bomb test site in New Mexico. Since 1951, the majority of nuclear tests were performed at the Nevada test site. During the nuclear tests in the USA in 1951–1956 in the area of Desert Rock, eight field training exercises using nuclear weapons were conducted in order to "…train soldiers correctly to perceive nuclear weapons.."

The UK conducted its first nuclear explosions in Australia at the Woomera, Maralinga test sites, and on Monte-Bello and Christmas islands; since 1962 all nuclear testshave been conducted jointl y with the USA at the Nevada test site

FRANCE conducted its early nuclear tests at the Sahara test site near the village of Reggan in Algeria; since mid-1966 all French tests have been conducted at the Mururoa and Fangataufa atolls in the Pacific.

CHINA has conducted all its nuclear tests at the nuclear test site near the lake Lobnor in the Sintkiang province.

THE USSR equipped two test sites for nuclear tests: the Semipalatinsk test site (approximately 150 km to the west from Semipalatinsk) and the North Test Site, on the Novaya Zemlya archipelago (Fig. 2.). The latter test site is the most favourable with regard to geographical, geological and economic parameters, and radiation and seismic safety. The archipelago, located north of the arctic circle, is subject to severe climatic conditions. Due to the low height of the sun above the horizon in summer, the sea and the land are weakly warmed. In winter, the sun is below the horizon for a long period, causing strong cooling of the land surface. A branch of the warm stream coming to the Barents Sea and air masses coming constantly from the Atlantic Ocean make the climate here milder. The complex relief (mountains near the sea, fiord-like bays) favours creation of local storm winds ("bora"), formed on the western shore of the island in the presence of an anticyclone in the east, and simultaneously approaching cyclone from the Barents Sea. Atmospheric circulation is determined by the character of interaction of the main baric formations – the Icelandic minimum, and the arctic and the Asian maximums. Cyclonic activity prevails, reaching its maximum in winter. In particular, the wind-rose, the parameter extremely important for long-term confinement of explosion products in the test zone, is stable here (Fig. 3.). The test site is removed from inhabited localities by several hundred kilometres.. Alienation of land for the test site did not have any noticeable negative impact on the on the economic activity in the region. At the North Test Site, tests could be conducted in various media (on the ground surface and underground, above the water surface and underwater, high in the atmosphere) in order to examine the effect of various nuclear blast factors on all types of weapons and military equipment.

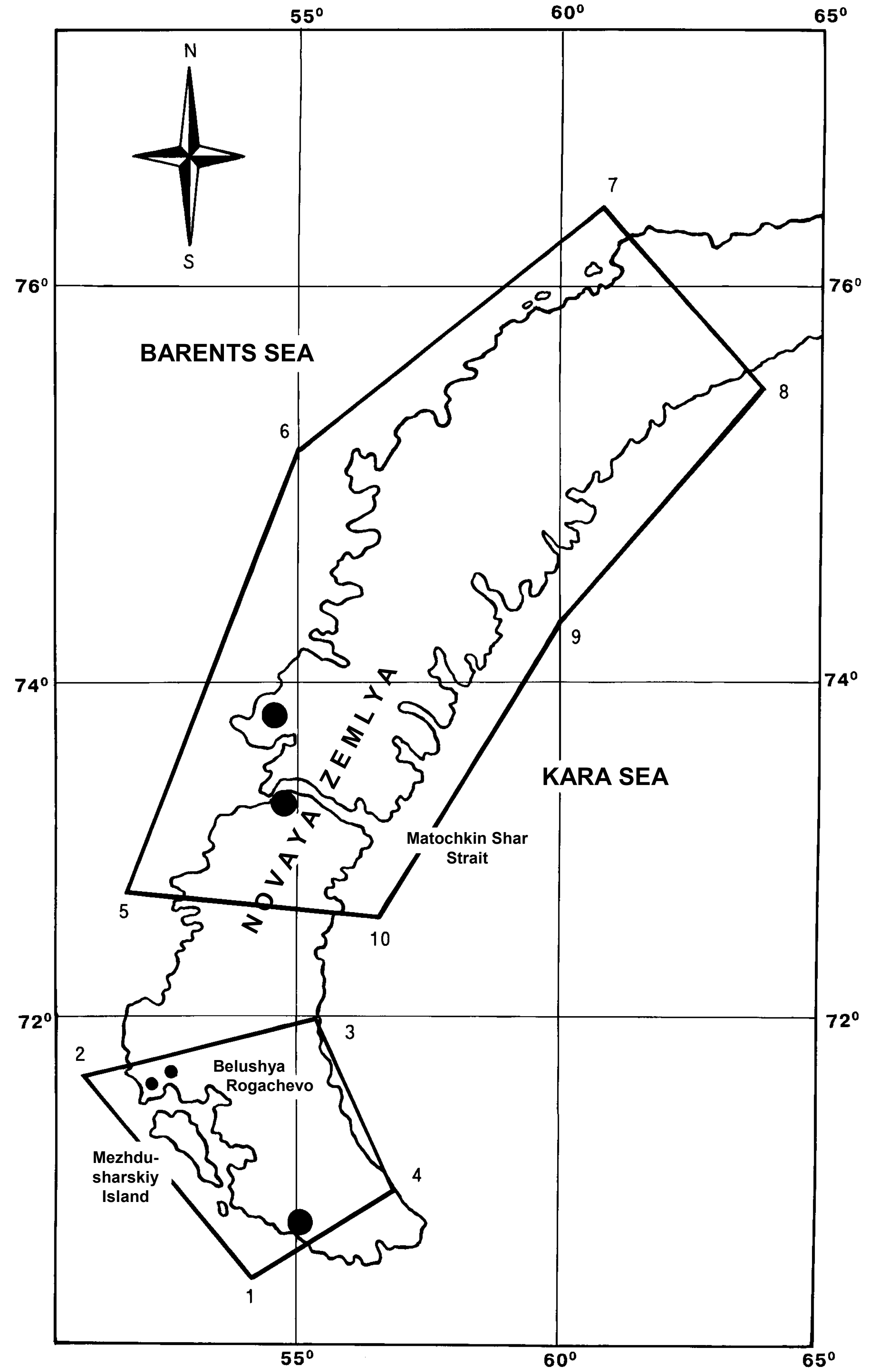


FIG. 2. Scheme of the North Test Site with geographical coordinates of its boundaries.

By the time of the first nuclear explosion in the USSR (29 August 1949), the USA had carried out eight nuclear bursts in three media; of these, two were nuclear airbursts aerial explosions in the course of combat deployment of nuclear weapons during the Second World War – bombing the Japanese cities of Hiroshima (06 August 1945) and Nagasaki (09 August 1945). By 1958,the United States had carried out more than 2.5 times more tests than the USSR (196 vs. 72).

— *During the moratorium on conducting nuclear tests declared by the USSR effective between 31 March and 30 September 1958, the USA detonated approximately 30 nuclear explosions in the atmosphere.*

— *In 1959 and 1960, the USSR and the USA did not carry out any nuclear tests.*

— *Nuclear tests reached their peak in 1961–1962: USA – 106, USSR – 94 (of which 56 were at the North Test Site).*

— *On 06August 1985, the USSR unilaterally declared a moratorium on underground nuclear explosions. The 18-month term of the moratorium was prolonged four times, till 26 February 1987. Later, there were no underground nuclear explosions at the USSR test sites from 19 August 1989 till 23 October 1990, and from 25 October 1990 till the present. During these periods, the USA performed 38 underground nuclear explosions, including tests for creating "third generation" nuclear weapons.*

— *Since 1990, the USSR has detonated only one underground nuclear explosion (North Test Site, 24 October 1990), whereas the USA carried out 19 tests(1990 – eight, 1991 – nine, 26 March 1992, 30 April 1992), while Francehas carried out 12 tests (1991 – six) and China three tests.*

— *The last nuclear explosion was detonated at the Semipalatinsk test site on 19 October 1989, and since 29 August 1991 this test site has been closed for nuclearweapons tests.*

— *The last nuclear explosion was detonated at the North Test Site on 24 October 1990, and since 26 October 1991,yet another unilateral one-year moratorium was declared on carrying out nuclear tests at this site.*

The last underground nuclear explosion within the framework of national economic development was set off on 6 September 1988, at present , no such explosions are being plqnned although the 1976 Peaceful Nuclear Explosion Ttreaty between the USSR and the USA and the 1990 Protocol to the Treaty ratified in 1990 allow such tests to be conducted.

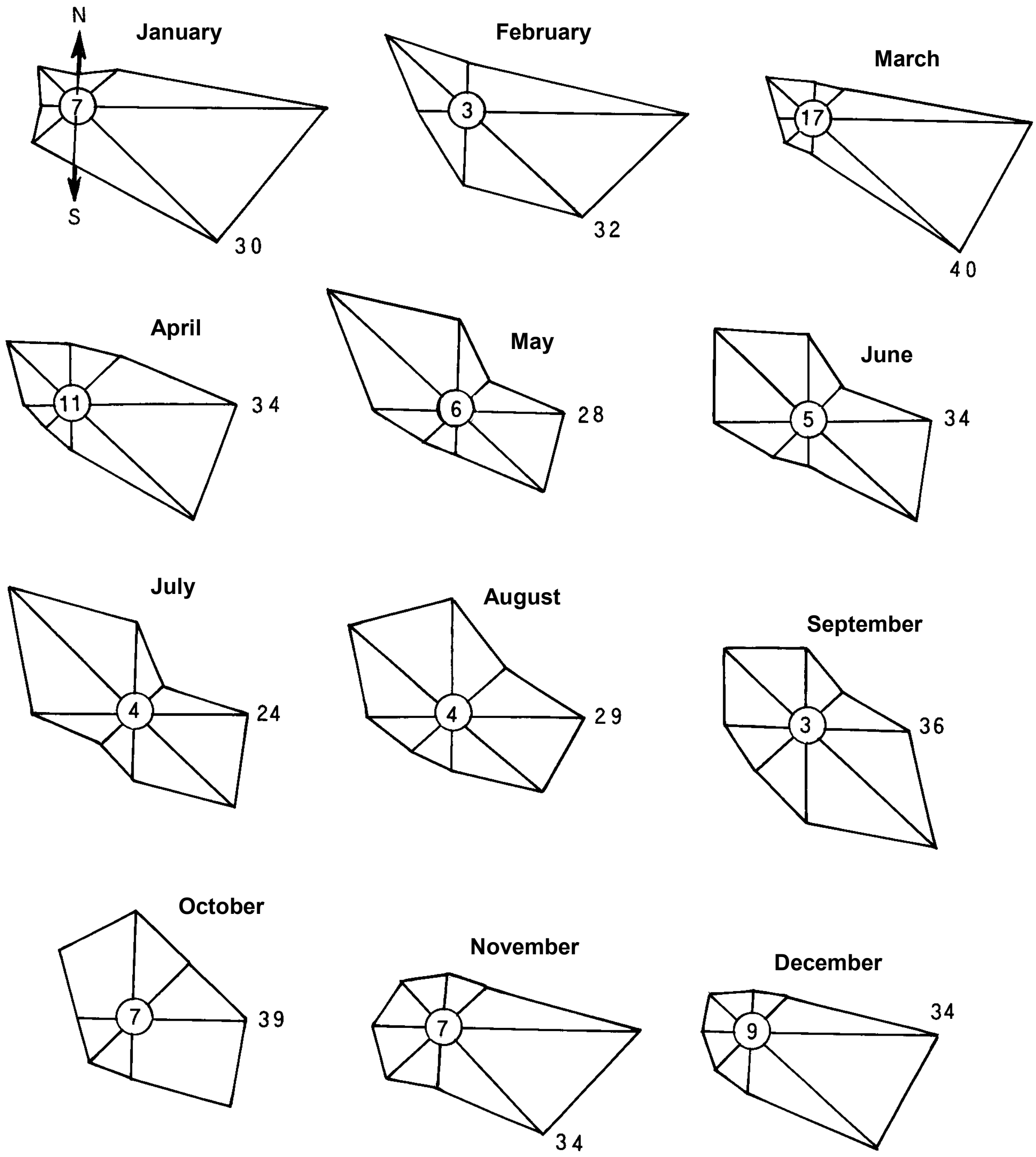
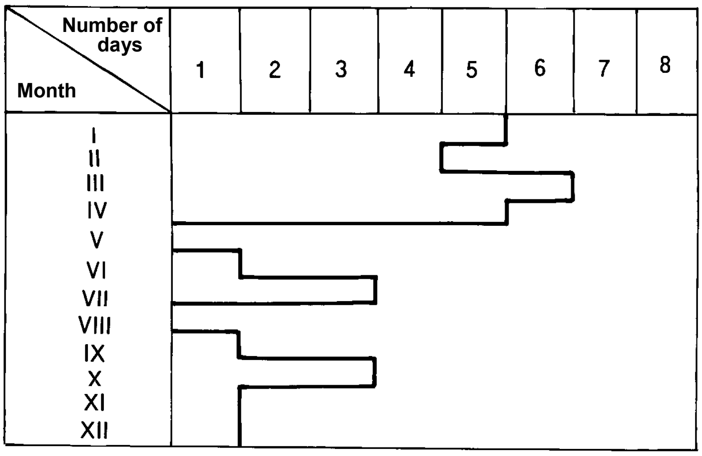


FIG. 3. Novaya Zemlya archipelago: climate and meteorological conditions.

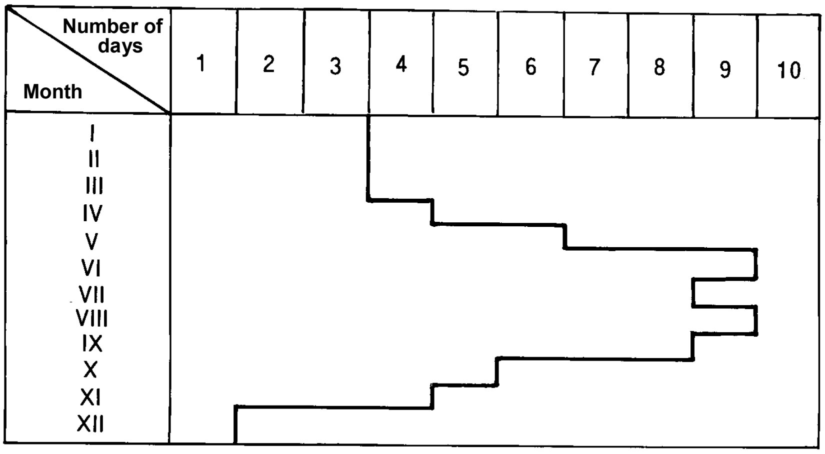
(a) wind-roses (in circles – the numbers of calm weather events, numbers – the maximum wind velocities on compass points, m/s)

Authors: A. Zabroda, A. Semenov

The number of clear days



The number of days with mists



The number of days with snowstorms

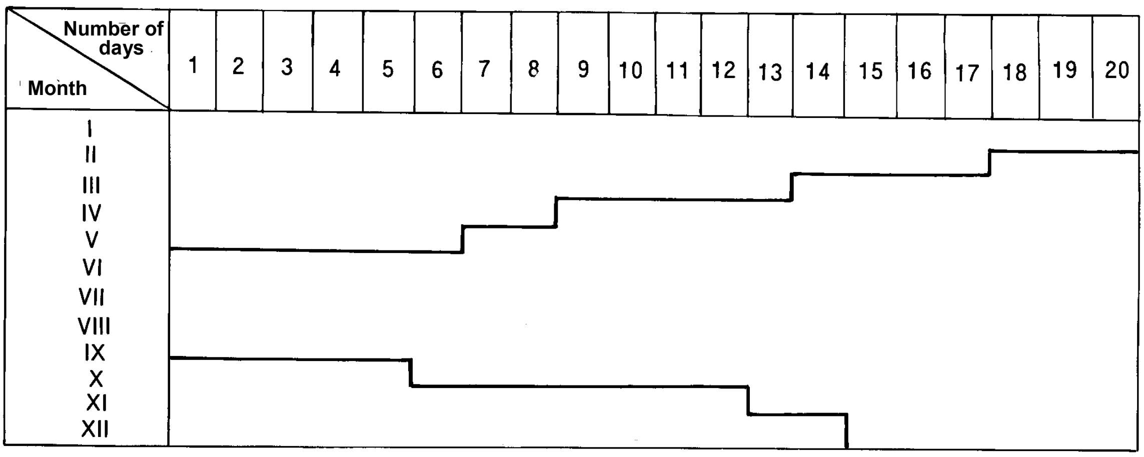
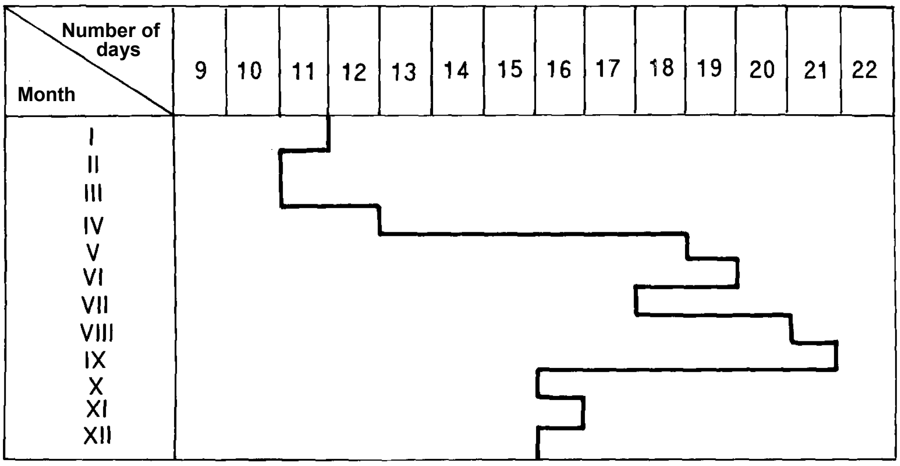


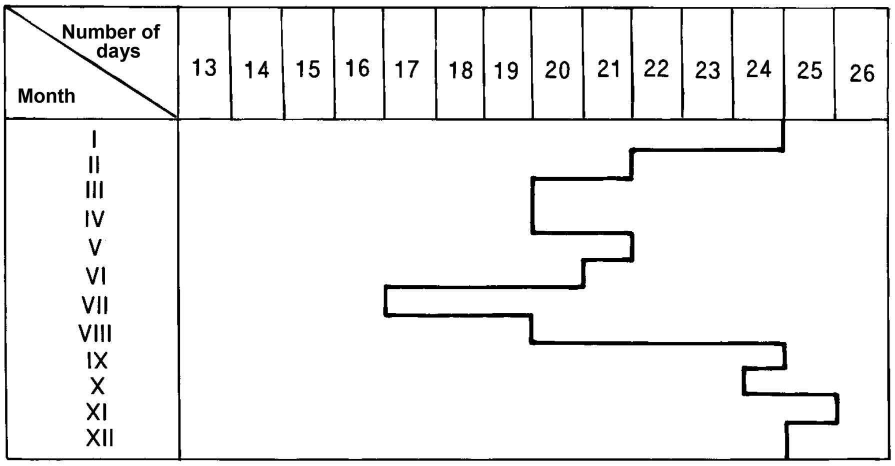
FIG. 3. (continued).

(b) Climatic factors.

The number of cloudy days



The number of days with precipitations



The number of days with wind >12 m/s

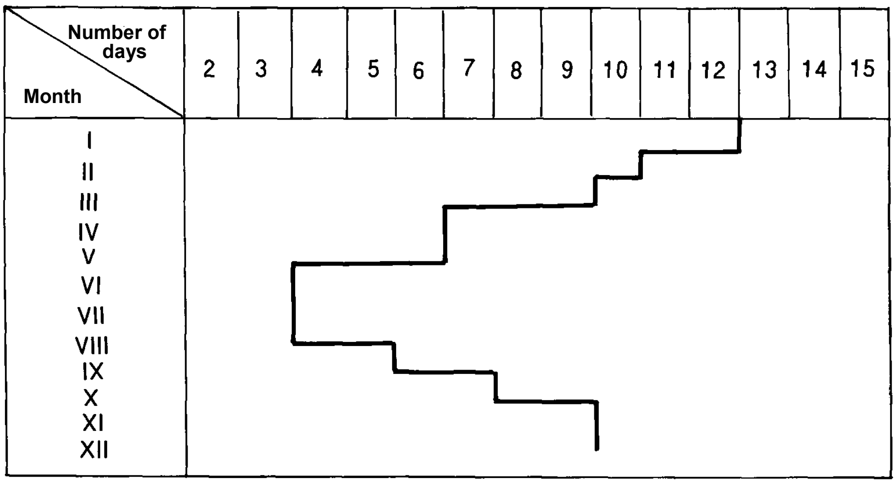


FIG. 3. (continued).

(b) Climatic factors.

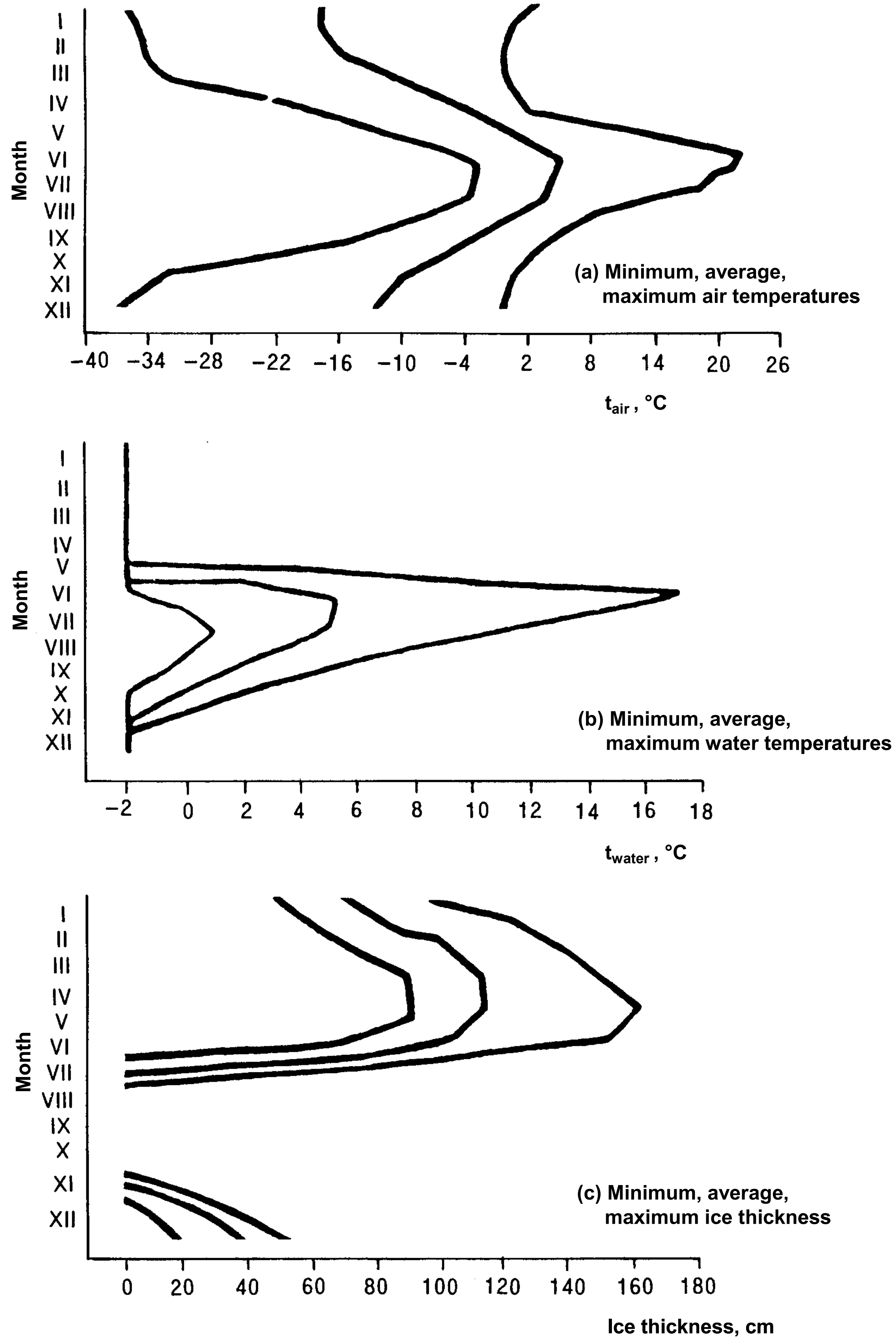


FIG. 3.b. (continued).

TABLE I. ICE REGIME

Date of:	Dates		
	Early	Middle	Late
First appearance of stable ice	13 September	5 November	6 November
First complete freeze	15 October	12 November	30 December
Breaking of near-shore ice	27 June	28 June	9 July
Complete clearing from ice	28 June	13 July	21 July

TABLE II. THE NUMBER OF DAYS WITH STORM ALERT

Month	Storm readiness								
	No. 1			No. 2			No. 3		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
I	1	8	4	3	6	2	8	11	4
II	1	0	0	5	6	0	8	14	2
III	1	3	0	2	9	0	5	11	0
IV	1	1	0	1	3	0	2	7	0
V	0	0	0	1	1	0	10	7	1
VI	0	1	0	0	0	0	4	5	2
VII	0	0	0	0	0	0	2	3	1
VIII	0	0	0	0	0	0	4	5	0
IX	0	0	0	1	2	0	4	8	0
X	0	0	0	0	1	0	4	8	0
XI	1	4	0	0	5	0	1	11	4
XII	1	3	0	2	6	0	4	8	1
Total per year	6	28	4	16	39	2	56	98	15

TABLE III. THE DATES OF SETTLING THE SNOW COVER

Date of:	Dates		
	Early	Middle	Late
Snow cover appearing	1 September	4 October	6 November
Formation of stable snow cover	3 October	6 November	2 December
Loosening of stable snow cover	26 May	11 June	28 June
Melting of snow cover	4 June	16 June	28 June

2.2. CHARACTERISTICS OF NUCLEAR TESTS

The energy yield distribution of nuclear tests and peaceful nuclear explosions on USSR territory: in Mt is shown in Table IV.

TABLE IV

North Test Site	Semipalatinsk Test Site	In other regions of the country	Total
~ 265	~ 17.4	~ 2.6	~ 285
The energy yield distribution of nuclear tests and peaceful nuclear explosions on USSR territory in%			
Test type	North Test Site	Semipalatinsk test site	In other regions of the country
Atmospheric	~ 84.1, including 2 on-water surface	~ 2.3	~ 0.35 (military exercises with application of nuclear weapons in the Orenburg region, on 14.09.54), and 10 aerial and high-altitude (H > 10 km) tests
Underground	~ 9.0	~ 3.8	~ 0.55
Underwater	< 0.01	-	-
Total sum of Nes	~ 93	~ 6.1	~ 0.9 (117 PNEs)

2.2.1. Distribution of nuclear tests in the USSR and the USA in energy groups

TABLE V

USSR			USA		
Energy release range W, kt TE	Number of performed nuclear explosions	W value averaged over ranges, thousands kt TE	Energy release range W, kt TE	Number of conducted nuclear explosions	W value averaged over ranges, thousandst TE
Below 20	457	4.57 (457)	Below 20	737	7.37 (737)
20–150	172	14.62 (172)	20–200	279	30.69 (279)
150–1500	57	47.025 (57)	200–1000	48	28.8 (48)
1500–5000	21	68.25 (21)	1000–5000	29	87.0 (29)
Below 10000	2	15.0 (2)	Below 10000	2	15.0 (2)[1]
> 10000	6	112 (6)[2]	> 10000	4	50.0 (4)[1]
Total	715[3]	261.965 (715)	Total	1032[3]	218.86 (1032)

[1] On the Bikini and Enevetak atolls in 1952–1958, the USA performed in the atmosphere two on-surface (31.10.51 and 28.02.54) and four on-water nuclear explosions (26.03.54, 25.04.54, 04.05.54 and 28.06.58) with an energy release of > 5.0 Mt TNT.

[2] Including the air nuclear explosion at the Northern Test Site on 30 October 1961, with the energy release of 50 Mt TNT.

[3] Of the total number of the nuclear explosions detonated in the USSR (715) and in the USA (1032), respectively: high-altitude – five and nine, air– 177 and 83, surface – 32 and 84, underground – 496 and 815, water surface– two and 36, underwater – three and five tests.

Information

The average energy release in the energy ranges was obtained by multiplying the average value in ranges by the number of nuclear explosions in each range. The division of the total energy release of nuclear tests and peaceful nuclear explosions performed in the USSR [285 Mt TNT (see Table II)] by the assessed average (260.05 Mt TNT) gives the correlation factor, which is assumed equal (the parity of nuclear armaments of the USSR and the USA recognized by specialists and the public). Thus, for the 1032 nuclear tests and peaceful nuclear explosions performed in the USA, the total energy release is assessed by the value $285 \cdot 218.86/261.965 \approx 238$*Mt TNT.*

2.3. MAIN INITIAL PARAMETERS FOR ASSESSMENT OF RADIATION CONSEQUENCES OF NUCLEAR EXPLOSIONS

The contribution of atmospheric nuclear tests performed by all countries to global radioactive contamination of the environment [6] is assessed as:

— surface nuclear explosions ($H < 35\ W^{1/3}$) – 12%

— aerial nuclear explosions ($H > 35\ W^{1/3}$) – 75%

— high-altitude nuclear explosions ($H > 10000$) – 3%

— from nuclear fuel cycles used for military purposes – 10%

— where H is the burst altitude, m; W is the explosion yield, kt.

The radionuclides formed in nuclear tests were mainly ejected into the stratosphere, where they were mixed and globally redistributed, and then began to fall out during a long period in various amounts to the earth's surface (global fallout). In their composition, the dose-forming nuclides are mainly long-lived fission products: caesium-137 ($T_{1/2}$ = 30.2 years), strontium-90 ($T_{1/2}$ = 28.6 years) and carbon-14 ($T_{1/2}$ =5730 years).

According to expert assessments, the total number of radionuclides that entered the stratosphere prior to 1981 was: caesium-137 - approximately $9.6 \cdot 10^{17}$ Bq ($26 \cdot 10^6$ Ci), strontium-90 - approximately $7.4 \cdot 10^{17}$ Bq ($20 \cdot 10^6$ Ci), and carbon-14 - approximately $2.2 \cdot 10^{17}$ Bq ($5.9 \cdot 10^6$ Ci). The contribution from atmospheric tests in the USSR completed by 1963 is: caesium-137 — approximately $1.8 \cdot 10^{17}$ Bq ($4.9 \cdot 10^6$ Ci), and strontium-90 — approximately $1.2 \cdot 10^{17}$ Bq ($3.2 \cdot 10^6$ Ci), i.e. approximately 20% of the total of the aforesaid radionuclides that entered the environment as a result of nuclear explosions.

Thirty years have passed since the end of the early atmospheric tests. During this period, due to natural decay, the amount of ^{137}Cs and ^{90}Sr has decreased twofold. The contribution of ^{14}C of test origin is now only 2.6% of the natural background of this radionuclide in the upper atmospheric layers under the effect of cosmic radiation due to the reaction with nitrogen nuclei in the air. Thus, the radiation danger from ^{14}C formed in tests is insignificant.

Since the seventies, the indicated activities of the main long-lived dose-forming radionuclides (caesium-137 and strontium-90) have caused an average level of background surface soil contamination on the territory of the country within $3 \cdot 10^3$ and $1.9\ 10^3$ kBq/m^2 (0.08 and 0.05 Ci/km^2), respectively.

When underground nuclear explosions were carried out, leakages of insignificant amounts of radioactive noble gases in the atmosphere could take place. This process occurred at the North Test Site at 27 underground nuclear explosions (UNEs), and resulted in generation in the atmosphere, due to radioactive decay of the noble gases, approximately $(9.2\text{-}18) \cdot 10^{13}$ Bq of caesium-137. As a result of an extended (2–5 day) retention of the explosion products over the territory of the test site due to the weather conditions, approximately 80% of this amount was deposited within the limited areas of the test site.

2.4. CURRENT RADIOLOGICAL SITUATION IN FAR NORTH

Of the 88 nuclear tests performed in the atmosphere, actually only one surface nuclear explosion (07.09.57) caused residual radioactive contamination on the test site area (zone A, Fig. 1.), then separated as an exclusion zone. Here, on a local plot of less than 10 m^2, the exposure dose rate in 1992 did not exceed 1 mR/hour (at the height of 1 m).

In the zone of underground tests, (zone B, Fig. 1.), the exposure rate of gamma radiation (ER) on a local plot with an area not greater than 1 km^2 is 50-60 μR/hour.

In the zone of aerial nuclear explosion (zone C, Fig. 1.), the ER on a local area covering approximately 0.5 km^2 does not exceed 50 μR/hour.

The mean density of the surface contamination of the remaining test site territory is for caesium-137 about 3.3 kBq/m^2 (0.09 Ci/km^2) and for strontium-90 about 2.2 kBq/m^2 (0.06 Ci/km^2); i.e. it does not differ from the mean background contamination in this region.

Note. At the North Test Site (and also at the Semipalatinsk test site), there is no need for wide-scale decontamination programmes, as was assumed by Greenpeace experts, whose landing penetrated on 8 October 1990, to the North Test Site into the local exclusion zone of the earlier UNE (02.08.87) where the ER is 80–100 μR/hour (see Section 2).

Also, there are no grounds to assume that "... such a big region as Novaya Zemlya has been turned into a nuclear dump", as is stated in one of the messages [5] on the basis of a survey of zone A of the site, where one surface and some underwater nuclear explosions were detonated, and where the EDR does not exceed 1 mR/hour on a local area.

One of the pathways of human exposure is the ingestion of radionuclides with food and water. In conditions of the far north, it takes place along the food chains lichen-reindeer-man and water-fish-man. During the period 1963–1990, the following data characterizing caesium-137 contamination were obtained.

TABLE VI

Monitored object	Caesium-137 concentrations, Bq/kg				
	1963	1969	1970—1978	1980—1988	1988—1990
Moss	222–260	260–370	300–550	220–440	150–180
Lichen	750–1700	1300–2700	750–1500	–	–
Reindeer meat	75–370	80–1100	80–370	80–180	40 – 75
Fish	2.6–3.7	1.1–1.8	3.0–3.7	2.6–3.7	2.6
Milk	–	0.2	0.56	0.110	0.037
Goose, Duck	–	–	15–22	11–15	7.5–15

The analysis of water samples has shown that concentration of ^{90}Sr, ^{137}Cs and tritium is at least by 100 times below the permissible concentrations levels for drinking water pursuant to the national standards for radiation safety (NRB–76/87).

The level of radioactivity in fish caught at Novaya Zemlya in 1985–1990 varied within the limits from 100 to 130 Bq/kg, and up to 90% of this activity was due to natural ^{40}K (the specific activity of different fish species caught in the world ocean is equal to 25 to 140 Bq/kg only due to potassium-40).

The dose to the body of reindeer from ^{137}Cs, ^{90}Sr and the natural radionuclides of Po(^{210}Pb) in 1964–1965 (the maximum of fallouts after the conclusion of nuclear tests in the atmosphere) was equal (in mSv/year):

TABLE VII

Region	^{137}Cs	^{90}Sr	^{210}Po	Total
Murmansk region	15	5	12	32
Komi Republic	12	2	4	18
Taimyr	5	2	9	16
Yakutiya (Sakha)	3	2	7	12
Chukotka	4	2	12	18

With regard to consumption of reindeer meat(the principal food product containing radionuclides), the population of the Far North is quite inhomogeneous. Residents of big cities (Murmansk, Vorkuta, Magadan and Norilsk) seldom eat raindeer meat , and their dose loads do not differ considerably from those for residents of Moscow and St. Petersburg.

The critical group for exposure is indigenous peoples of the Far North (reindeer herdsmen). They consume daily, on the average, about 250 g of reindeer meat Moreover, an additional dose (about 10%) due to the daily use of snow for obtaining drinking water and cooking, consumption of freshwater fish and meat of ptarmigans for food. This critical group numbers 30 000 people. The remaining population (300 000), including inhabitants of small towns and villages, is in an intermediate position between reindeer herdsmen and urban population (approximately one million). The seasonal dependence of caesium-137 content in the body of reindeerherdsmen who eat freshly slaughtered reindeer meat corresponds to the level in the reindeer: at the end of summer, the minimum is recorded, and at the end of spring, the maximum. Among Alaska Eskimos, extremes are noted during other periods, because Eskimos do not herd reindeer, but hunt them twice a year. Reindeer meat from autumn hunting with minimum contamination is consumed in winter, and accumulation of caesium-137 in the body of Eskimos is at a minimum at the end of winter. Hunting from the end of winter gives the maximum accumulation of radionuclides at the end of summer.

As a result of these radiobiological characteristics, four sources of exposure can be identified for the critical population group (reindeer herdsmen):

— the average dose of the world population from natural background, which is (according to the latest UNSCEAR assessments) approximately 2 mSv/year;

— the dose from medical exposure, which is approximately 1 mSv/year;

— an additional natural dose due to specific features of the food chain lichen–reindeer–man from lead-210, bismuth-210 and polonium-210, which is approximately 1 mSv/year; and

— an additional artificial dose from caesium-137 and, to a lesser extent, from strontium-90 due to the same food chain, which is, on average, 1 mSv/year, and 0.01 mSv/year for city dwellers

There seems to be no correlation between radiation exposure and cancer mortality for the indigenous population of the far north. Increased mortality of reindeer herdsmen of oesophagus cancer was initially regarded as the consequence of radiation impact along the food chain lichen–reindeer–man. However, this conclusion appears doubtful because, in particular, in the western districts (Murmansk region etc.), where the radiation doses from caesium-137 are five times higher than in the eastern ones (Yakutia, Chukotka), cancer mortality is, nevertheless, three–four times lower. These and other specific health features of reindeer herdsmen (elevated cataract incidence, and a lower immunity reaction) and certain other causeand effect relationships call for more detailed investigation.

2.5. CRITERIA FOR RADIATION AND SEISMIC SAFETY OF UNDERGROUND NUCLEAR TEST EXPLOSIONS

In accordance with recommendations of experts from the independent interdepartmental expert commission on assessing the radiation and seismic safety of underground nuclear tests, enhanced environmental requirements must be adhered to in carrying out each specific underground nuclear explosion.

Radiation safety

Radiation safety is reached by the exclusion of dynamic release of aerosols and, in the case of radioactive inert gas (RNG) leakages, by providing conditions under which the EDR at the boundary of the test site in the given sector of propagation of the RNG jet spreading should not exceed the range of fluctuation of the natural radioactive background. In this case, fallout of radioactive depositions outside the national boundaries of the State is ruled out, which is one of the principles of adhering to the Moscow Treaty of 1963.

This requirement was satisfied by the proper choice of test site and of depth for the nuclear device emplacement, and by the proper adherence of the stemming complex in the tunnel or borehole. This would ensure containment of the explosion products in the rock massif (Figs 4. and 5.) by long-term (thousands of years) burial of refractory long-lived radionuclides formed during an underground nuclear explosion through their localization and dilution in the mass of the rock melted by the explosion in the zone of the nuclear cavity.

Note: The cavity of an underground nuclear explosion and the adjacent fracturing zone can be considered as being similar to long-term radioactive waste storage sites. On Novaya Zemlya and other test sites, radioactive zones have been formed, each being storage for radioactive waste of explosion origin. Moreover, the principal radionuclides are solidly vitrified in the molten rock mass 400–800 t per one kiloton of the explosion energy equivalent. Their total activity is relatively low. Thus, in a standard generated unit of a nuclear reactor with the electric power of 1 GW due to uranium fission approximately 1 t of fission radionuclides is formed. At a standard underground nuclear explosion only 200–600 g(≈ 3–10 kt) are produced, and 80–90% of them are concentrated in the melt 'lens' at the bottom of the underground nuclear explosion cavity. There they are inaccessible for leaching out by groundwater, even if the latter should penetrate the cavity.

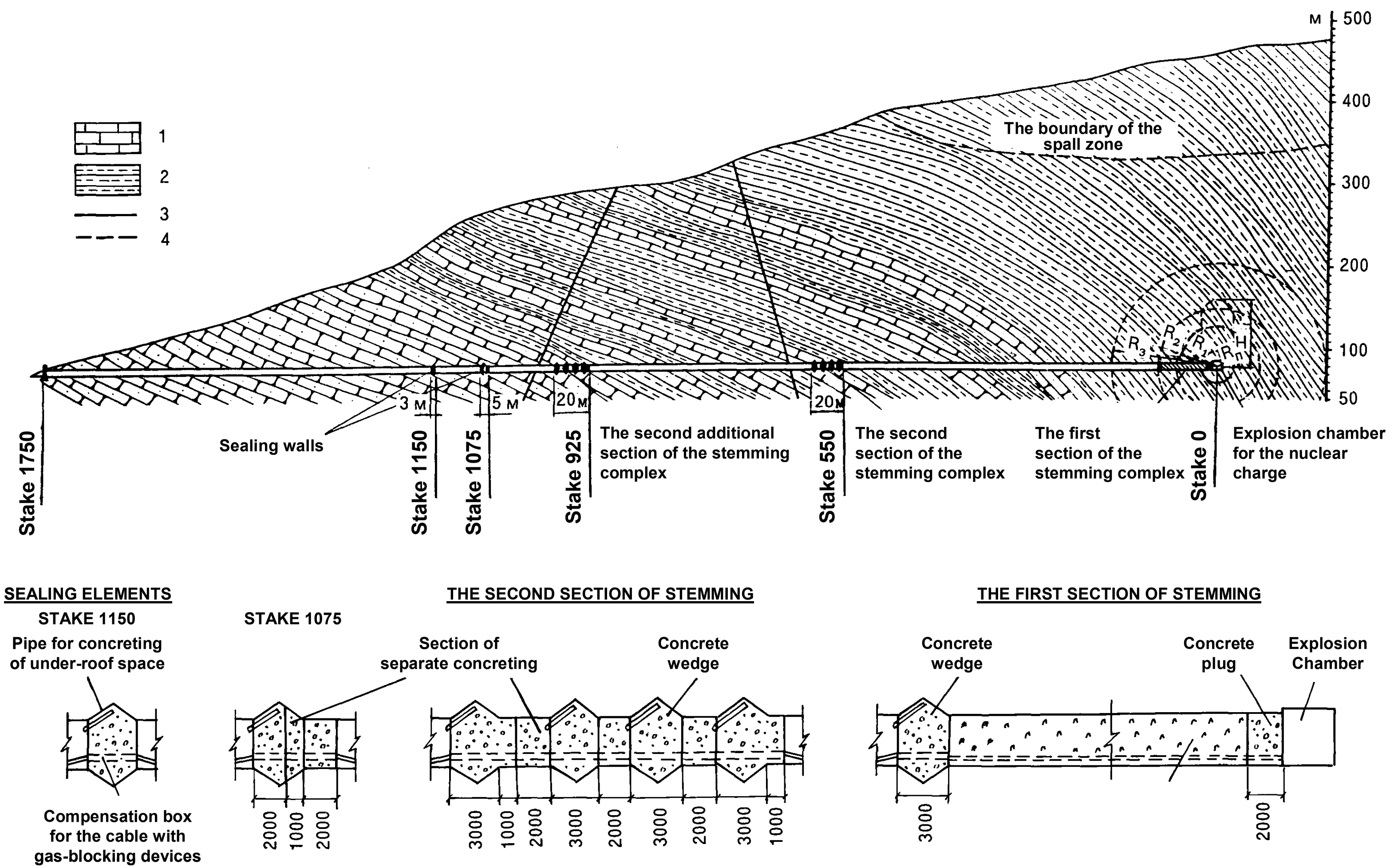


FIG. 4. Standard mine working tunnel with the stemming complex.

1 – quartz sandstones; 2 – mica shales; 3 – tectonic cracks; 4 – forecasted zones of the explosion mechanical impact: R_c – cavity radius, R_1 – radius of fracturing zone, R_2 – radius of macrocracks zone, R_3 – radius of microcracks zone.

Authors: E.P. Kozlov, A.I. Kurkin.

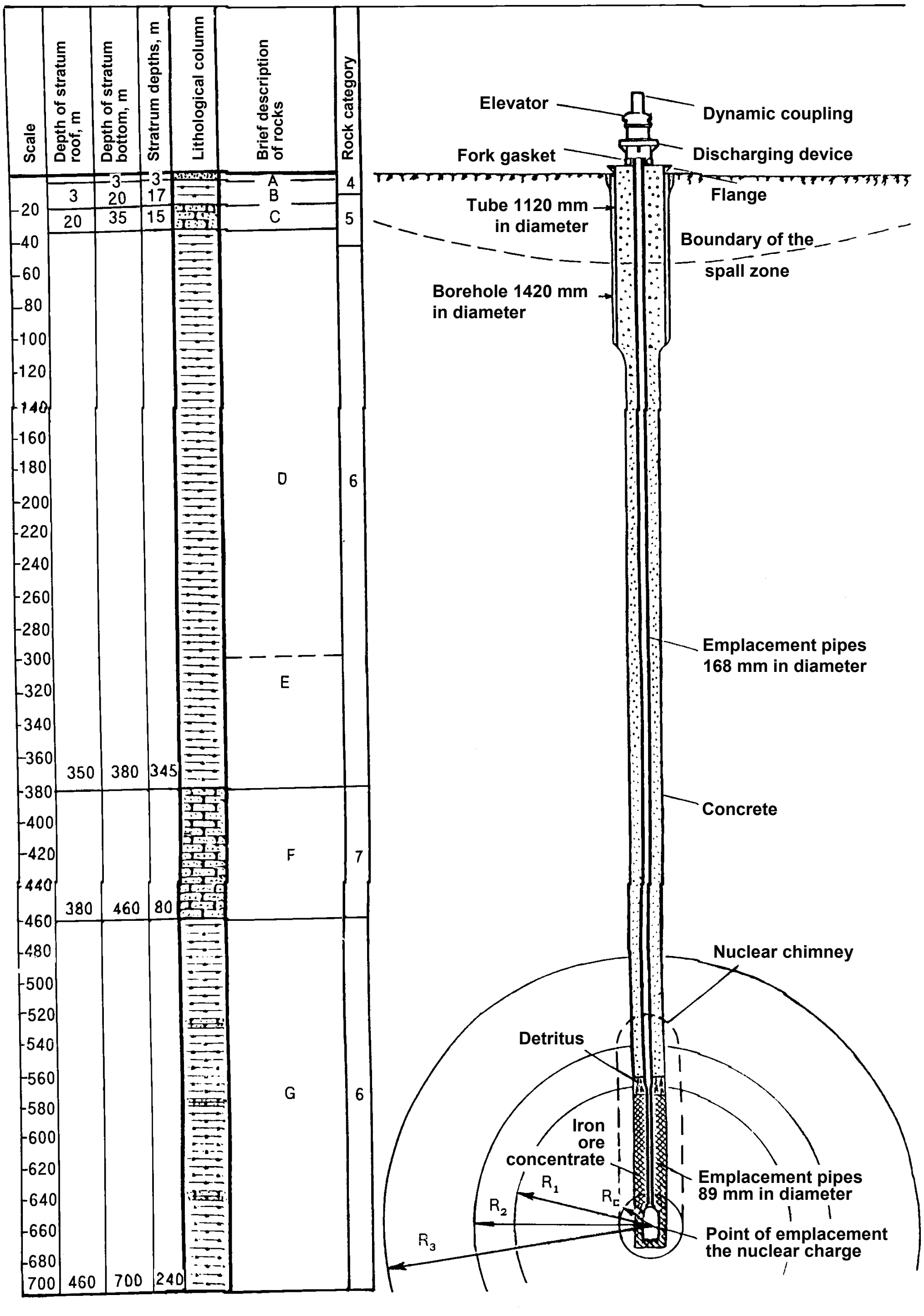


FIG. 5. Standard mine working (borehole).

A – detritus, gruss with loam filling; B – alevrolites; C – alevrolites with sandstone. Down to the depth of 25 m – the zone of exogenous fissuring; D – alevrolites with frequent thin layers of quartz and feldspar sandstones and multiple thin calcite veins; E – the boundary of perennial permafrost rocks; F – quartz and feldspar sandstones with frequent layers of alevrolites; G – alevrolites with rare thin layers of quartz and feldspar sandstones.

R_c – cavity radius, R_1 – radius of fracturing zone, R_2 – radius of macrocracks zone, R_3 – radius of microcracks zone.

Authors: E.P. Kozlov, V.F. Dorodnov

The main criteria for providing radiation safety when determining the conditions for each nuclear test are:

- geological, physical and chemical properties of the rock on the plot chosen for the test (jointing, gas and moisture content etc.);
- placement depth of the nuclear device, determined depending on the site characteristics; and
- safety of the stemming complex provided by special engineering measures.

Besides the aforesaid criteria, weather conditions are also used. Thus, with consideration for different accident scenarios, underground nuclear explosions at the North Test Site were conducted, as a rule, in conditions when the air masses above the test site were motionless or fairly still.

The choice of test location should be made with consideration for the physical and chemical properties of local rock. The conditions to be observed are:

- absence of tectonic faults and technogenic cracks in the enclosing rocks within a radius of up to 100 $m/kt^{1/3}$;
- gas content of the rocks at 1000°C no greater than 15% of the mass;
- absence of carbon-containing rocks in the zone of high thermal impacts, i.e. within a radius of less than 4 $m/kt^{1/3}$;
- absence of water-bearing horizons connected with the zone of free water exchange; and
- filtration factors of the existing rocks no greater than 10^{-3}–10^{-4} m/day.

The existing rocks should provide safe burying of the explosion products by limiting the transfer to the biosphere (via hydrogeological channels) and minimize the possibility of their anthropogenic impact (in the case of technological intrusion in the explosion zone).

The positive role of perennial permafrost rocks present at the North Test Site should be noted. They are one of the natural barriers that hinder migration of radioactive products from the explosion zone outside the melting zone. Assessments of the explosion thermal impact show that the maximum radius of the melting zone of perennial permafrost rocks at an explosion yield of 12–15kt does not exceed 85 m from the explosion centre, and at 100 kt does not exceed 160 m (Fig. 6.).

At the North Test Site, underground nuclear explosions were performed at depths of 90–120 $m/kt^{1/3}$ or greater, depending on geological conditions on the chosen test location (site, area).

Also, special engineering measures were undertaken for stemming tunnels and boreholes, providing localization of aerosol products under ground and maximum delay in seepage of RNGs to the atmosphere (many of the engineering solutions are classified as ‘know-how’ and are protected by patents).

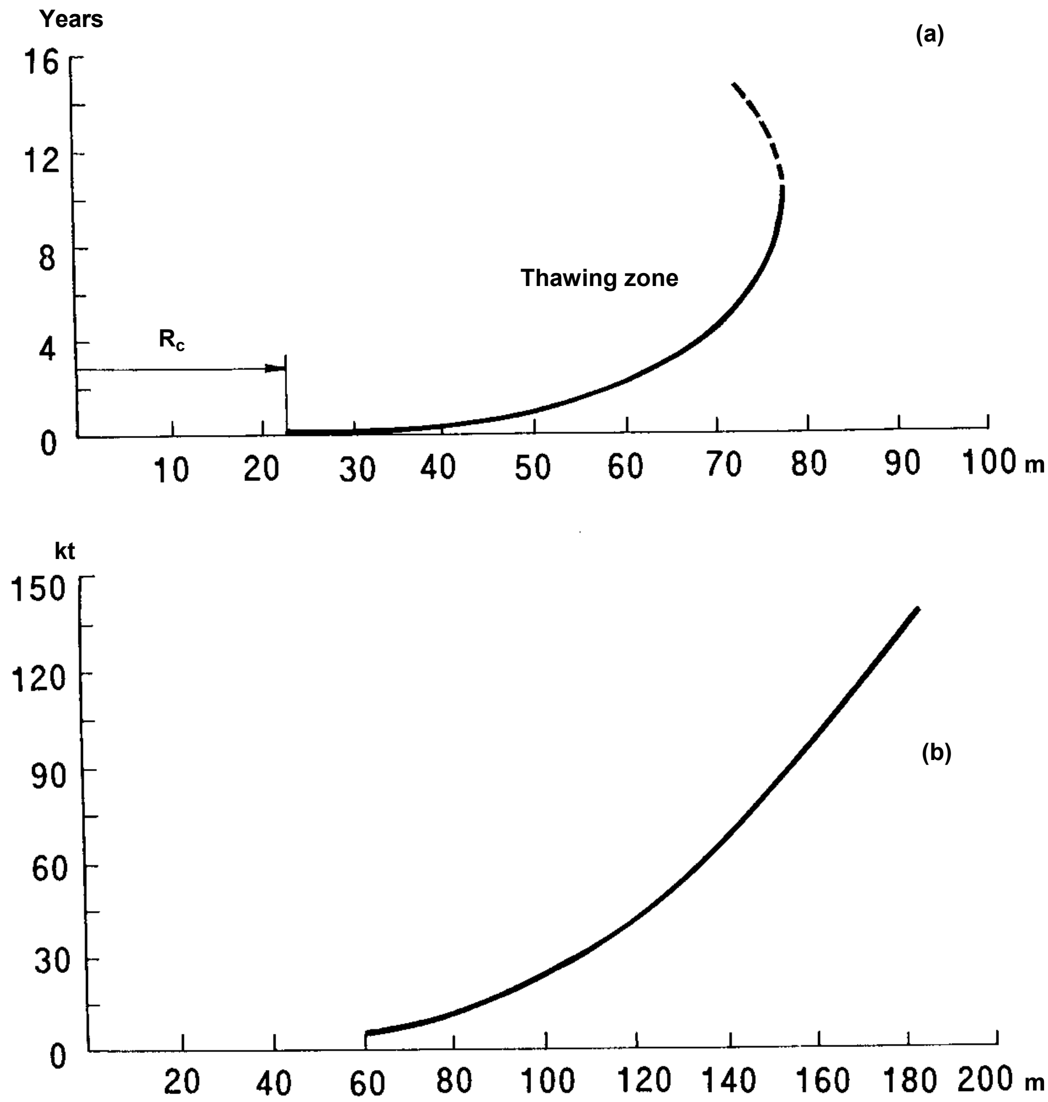


FIG. 6.

(a) Warming dynamics for perennial permafrost rocks around the cavity formed by a 12-kt nuclear explosion

(b) Maximum possible distribution of thawing zones in perennial permafrost rocks around cavities formed by nuclear explosions with various yields

Authors: V.G. Abalakin, V.F. Dorodnov

Moreover, with consideration for possible accidents, underground nuclear tests were carried out, as a rule, when no considerable motion of air masses above the test site had taken place for a long time. It was taken into account that dilution of the injected admixtures by 10^{10}–10^{12} times takes place already during the first one–three hours. For the North Test Site, with transfer of RNG with air masses not farther than 100 km from the explosion location, the exposure dose in the nearest settlement, above which propagation of the RNG is possible, will not exceed 20 μSv.

Note. For comparison: such a dose is approximately 50% of the dose which couples additionally expose each other to while sleeping in a common bed due to the presence of natural ^{40}K in their body.

It should be stated that, of 39 underground nuclear tests performed at the test site, only two (on 14.10.69 and 02.08.87) were accompanied by release to the earth`s surface of insignificant amounts of radioactive products, which caused non standard radiation situations in the test region. At the same time, statutes of paragraph 1b of Article 1 of the 1963 Moscow Treaty were not violated at any of these tests.

Seismic safety

At the North Test Site, for all possible scenarios of underground nuclear explosions with a yield equivalent not greater than 150 kt, the intensity of seismic impact of nuclear tests on the region, i.e. on the mainland, the islands of Spitsbergen and Franz Josef Land, and on the greater part of the Novaya Zemlya archipelago itself, is so weak that it cannot be assessed even within the seismic scale MSK-64, much less be felt by the people.

Note. Usually it is taken into account that natural oscillations of buildings and constructions are within an interval of 0.1–0.5 sec. Therefore, only volume waves with periods less than 1 sec. are seismically dangerous.

The influence of underground nuclear explosions on the natural tectonic process occurs due to relaxation of tectonic tension in the destruction zone around the point of explosion, and to tectonic shifts along the fault (where the explosion plays the role of a trigger). However, this process, as monitoring of aftershock shows, is limited by the zone of influence of the explosion on the media within the radius of inelastic deformations, i.e. at a distance of about 1 km from an explosion with the yield equivalent of 15 kt. This radius determines the volume of the geophysical media from which the tectonic energy can be released, and the magnitude of this energy. Assessments based on observation show that the released energy is less than the explosion energy. Therefore, the explosions do not cause catastrophic tectonic phenomena; on the contrary, their action is local release of stress in the region due to a series of small induced earthquakes.

2.6. SCIENTIFIC SUPPORT OF TODAY’S RADIOLOGICAL RESEARCH RELATED TO NORTH TEST SITE ACTIVITY

The studies were performed within the complex research programme for the radiation and sanitary-ecological situation at the North Test Site and adjacent regions (Region 2), of 1991 on by experts from various scientific research institutions (Fig. 7.) using a systematic approach that coordinated the investigation results with social and medical demographic factors (Fig. 8.).

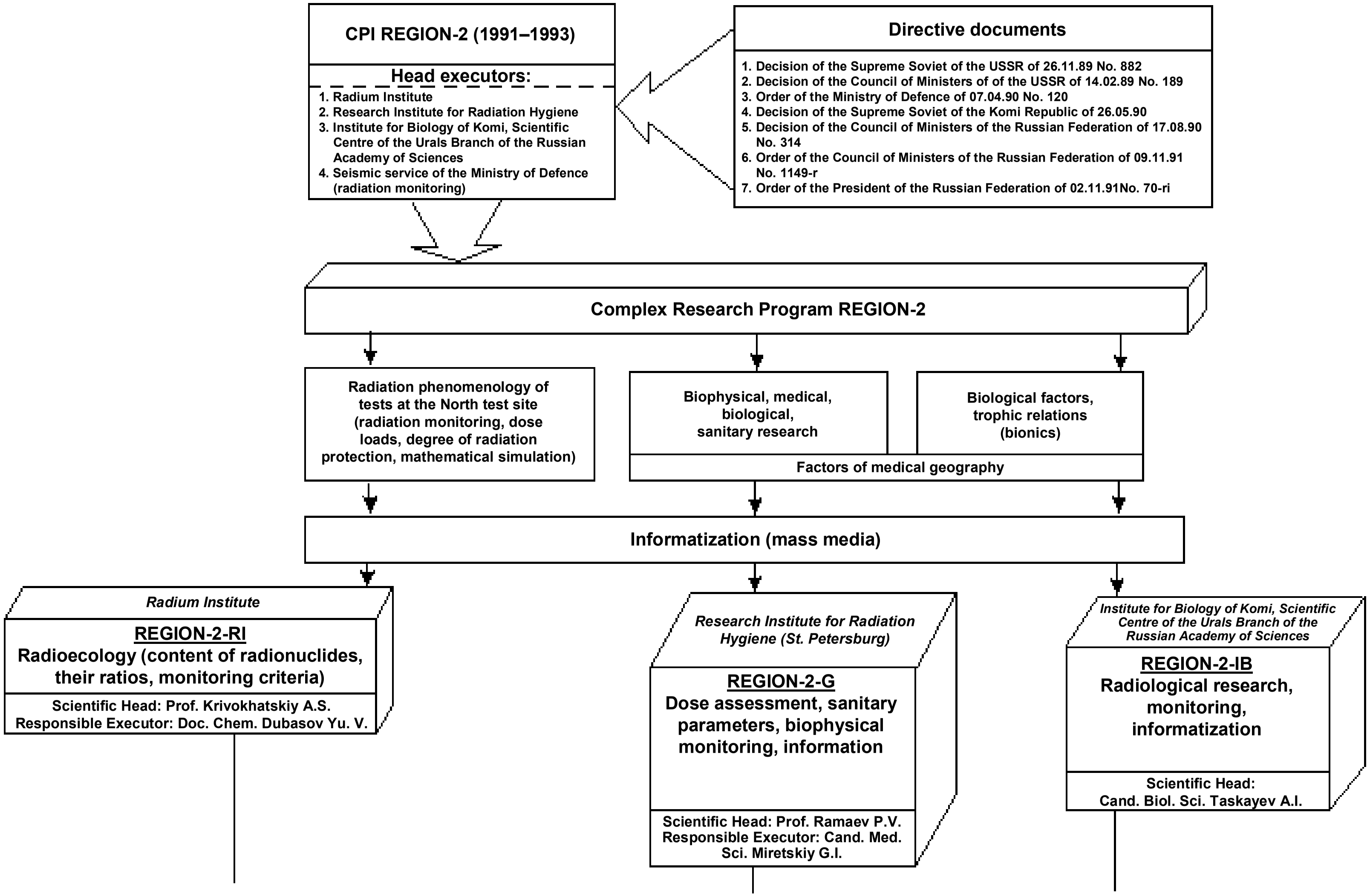


FIG. 7. Co-operation of research collectives in the complex programme of radiological investigations (CPI) of the North test site and adjacent territories (REGION-2).

Authors: A.M. Matushchenko, A.L. Maltsev

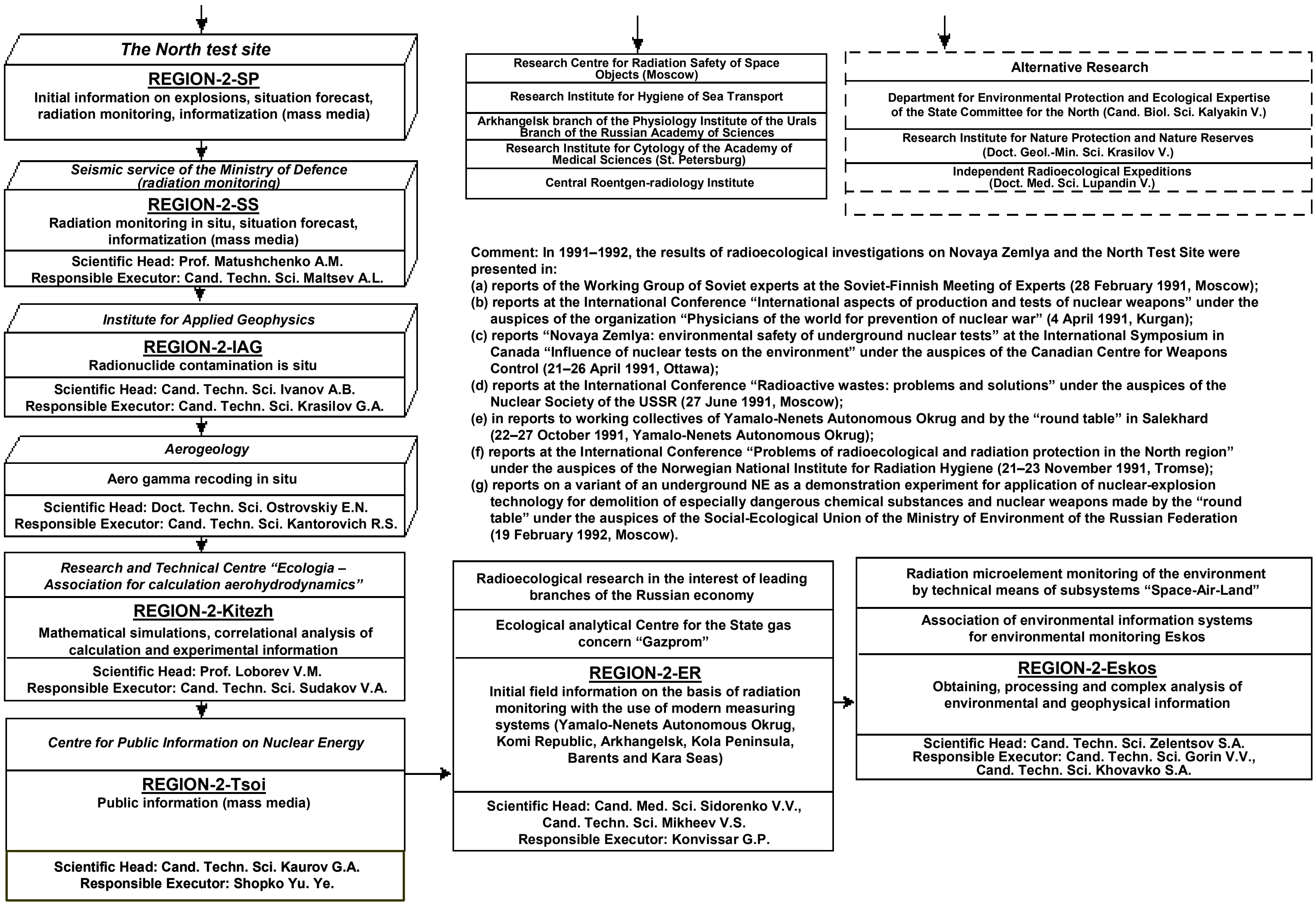


FIG. 7. (Continued).

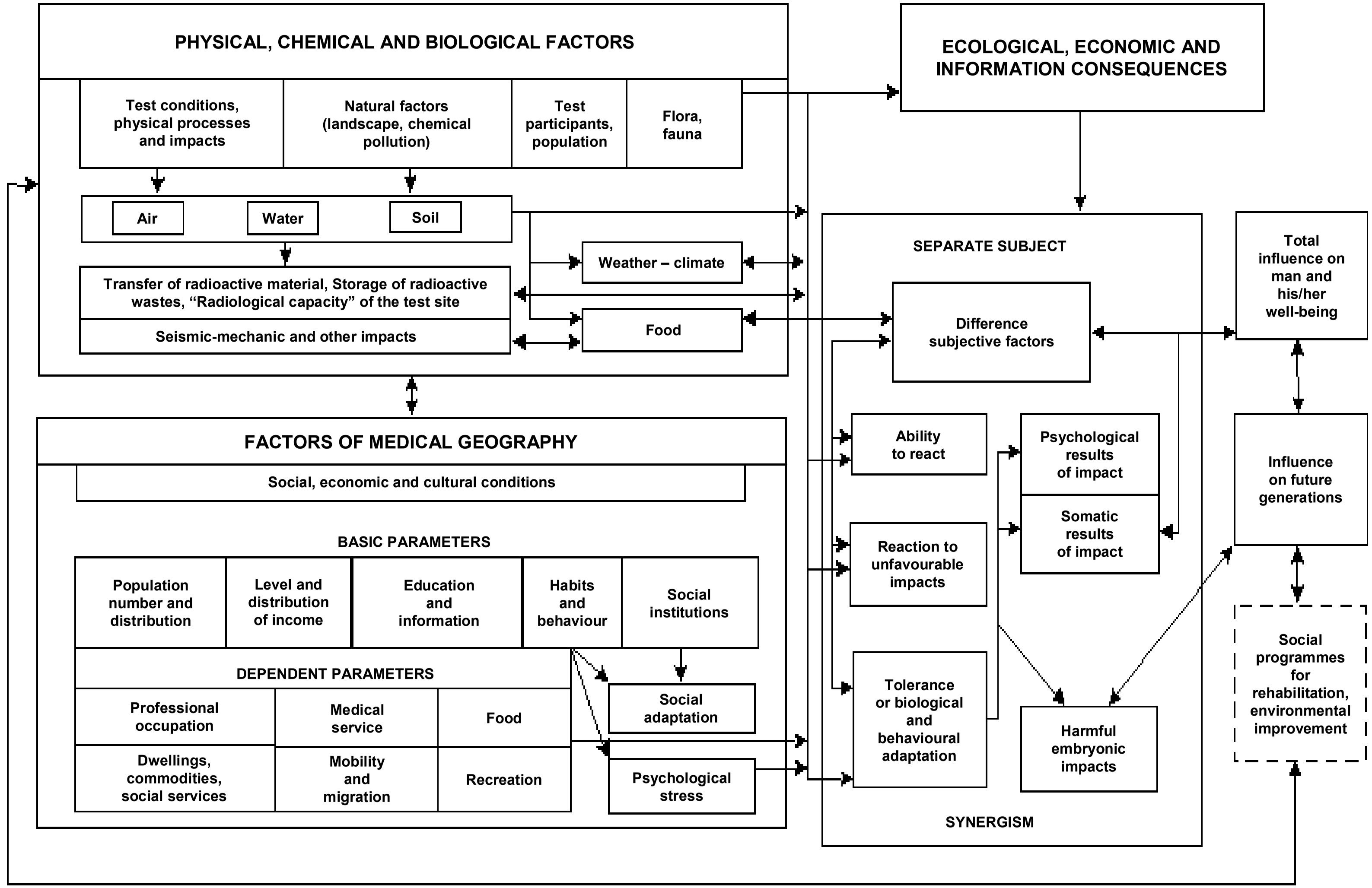


FIG. 8. System approach to the integrated studies of the test site environmental effects.

Authors: V.G. Gorlov, A.M. Matushchenko

2.7. INFORMATION ON THE NORTH TEST SITE

These efforts have been carried out in accordance with the Decision of the Supreme Council of the USSR of 27 November 1989 *On urgent measures of environmental remediation of the country* and of the Council of Ministers of the USSR of 14 February 1990 *On providing fulfilment of the Decision of the Supreme Soviet of the USSR of 27 November 1989*, and in accordance with the Decision of the Commission of the Deputy Chairman of the Council of Ministers of the USSR *On preparation of publications in the mass media about radiation situation at and around the North Test Site in comparison with other regions of the country and distributing them to editorial boards of central, republican and regional newspapers* (Protocol # BI-2259 of 30.05.90) and subsequent decisions of governing bodies of the Russian Federation.

The main results were presented in:

(1) reports and information documents of the heads of the Ministry of Atomic and Energy Industry, Ministry of Defence, the State Committee on Hydrometeorology, and Ministry of Health at hearings during the 2nd Congress of People's Deputies of the USSR on the issue of nuclear tests (December 1989);

(2) information documents prepared by experts from the Ministry of Defence and the State Committee on Hydrometeorology to the Supreme Council of the Komi Republic (May 1990) and on national television reports about nuclear tests at the North Test Site;

(3) reports to peoples' deputies of the USSR, Russian Federation, Komi Republic, representatives of the Arkhangelsk region and media correspondents visiting the North Test Site (May 1990, June 1991);

(4) a special publication of the bulletin of the Centre for Public Information on Nuclear Energy of 6 June 1990 *Members of the Government of the USSR and peoples' deputies of the USSR visiting the North Test Site* (with presentation of initial data on the radiation situation at the site in accordance with Protocol # BI-2259 of 30.05.90, for the first time in history);

(5) a reference memorandum for mass media in the Arkhangelsk region, Komi Republic, Yamalo-Nenets Autonomous Okrug *On the current state of radioecological situation on the Novaya Zemlya archipelago and adjacent territories of the far north* (July 1990);

(6) a report by the leadership of the Ministry of Atomic and Energy Industry, Ministry of Defence, the State Committee on Hydrometeorology to the chambers of the Supreme Council of the USSR at the discussion of ratification of the 1974 and 1976 treaties between the USSR and the USA (October 1990);

(7) reports of the working group of experts at the Soviet–Finnish meeting of experts on *Novaya Zemlya: environmental safety of underground nuclear tests* (Moscow, 28.02.91);

(8) information documents of experts from the Ministry of Defence and Ministry of Health about nuclear tests at the North and Semipalatinsk test sites at the international conference *Medical aspects of nuclear weapon production and testing* carried out under the auspices of the international organization Physicians of the World for Banning Nuclear weapons (Kurgan, 4–6 April 1991);

(9) reports at the International Conference of the USSR Nuclear Society *Radioactive waste: problems and solutions* and *The North Test Site: radioecology and radiation safety* (Moscow, 27 June 1991);

(10) in reports to information meetings proposed by the People's Deputy of the Russian Federation, A.N. Butorin, with representatives of Greenpeace, on the issue of tests at the Novaya Zemlya test site (Moscow, 2 September 1991, 18 March 1992);

(11) reports to the meetings with working collectives of the Yamalo-Nenets Autonomous Okrug on the radiation situation due to the operation of the North Test Site (22–27 October 1991, in the towns of Nadym, Salekhard, and the villages of Panderka, Yar-Sale, Yamburg, Aksarka);

(12) reports by representatives of the North Test Site to the first organizational conference of the public movement *To the novaya Zemlya* (Arkhangelsk, 16–17.11.91);

(13) reports to an international conference in Norway on *Problems of radiological and radiation protection in the northern region* (Tromse, 22–23.11.91);

(14) publications and interviews conducted in 1990–1992 in the mass media at the national and regional levels on the issues of nuclear tests and the related radiation situation: *Trud, Pravda, Izvestiya, Krasnaya Zvezda, Pravda Severa, Istok, Krasnoye Znamya, Molodyozh Severa, Krasnyi Tundrovik, Krasnyi Sever, "Rabochiy Nadyma, Tumenskaya Pravda, Morskoy Sbornik, Enegiya* journal, and bulletins of the Centre of Public Information on Nuclear Energy etc. (see references in Section 4);

(15) reports presented to a round table" held by the Socio-Ecological Union on *Destruction of chemical substances during underground nuclear explosions and the influence of this technology on Novaya Zemlya* – from the viewpoint of a possible demonstration experiment on the use of nuclear explosion technology for destroying chemical weapons (Moscow, 19 February 1992); and

(16) *Reference data on the issue of carrying out the State ecological expert examination of the Novaya Zemlya archipelago and adjacent territories*, presented to the Supreme Council of the Russian Federation on issues of the environment and of efficient use of natural resources, and to the Committee of the Supreme Council of the Russian Federation on issues of defence and security (Moscow, 26 May 1992).

2.8. NOVAYA ZEMLYA – NEVADA (QUESTIONS AND ANSWERS)

V.P. Dumik, N.P. Filonov, K.V. Kharitonov, Yu.E. Shipko

Below are the most frequently asked questions about the Nevada test site (NTS) in the USA and the answers to them taken from the report of a group of Finnish experts to the Finnish Ministry of Foreign Affairs in 1991, and the answers to these questions as applied to the Novaya Zemlya test site prepared by specialists of the Ministry of Defence and the Ministry of Nuclear Energy of the Russian Federation.

Questions	**Answers**	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
When and where was the first nuclear explosion set off?	On 16 July 1945 near Alamogordo, New Mexico. this test, entitled *Trinity*, had a yield of 21 kt and was detonated on a tower.	On 29 August 1949 at the Semipalatinsk test site. The yield of the nuclear device detonated on a tower approximately 30 m high was under 20 kt.

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
What is the total number of nuclear tests performed on national territory?	As of 1 March, 1990, the USA reported 827 unclear tests. Note (auth.): according to Russian monitoring data, by 1 January 1992, the USA had performed 1093 nuclear tests in different regions of the globe.	As of 1 January 1991, 715 nuclear tests had been carried out on national territory.
How many tests were carried out at the test site?	As of 1 March 1990, 699 tests had been carried out at the NTS.	As of 1 January 1992, 130 tests had been carried out at the test site.
What was the largest test carried out in the atmosphere at the test site?	The Hood test, with a yield of 74 kt, carried out over Yucca flats on a balloon on 5 July 1957.	The aerial explosion with a yield of about 50 Mt carried out on 30 October 1961, at an altitude of approximately 3.5 km.
Which nuclear test was the largest in the State?	A nuclear test with a yield of 15 Mt on the Bikini Island, on 28 February 1954.	An air explosion with a yield of approximately 50 Mt carried out on 30 October 1961 at the North Test Site.
What was the yield of the nuclear bombs dropped on Hiroshima and Nagasaki?	15 and 21 kt, respectively.	
How old is the test site, and when was the first test conducted there?	The NTS was created in 1950. The first test, named *Able*, was performed on 27 January 1950. A bomb with a yield of 1 kt was dropped from a plane above the Frenchman flat.	The decision to create the North Test Site was made by the Government on 31 July 1954. The first test was carried out on 21 September 1955 (underwater).
Have nuclear tests been conducted beyond the test site boundaries?	Yes, in New Mexico, Colorado, Mississippi, Alaska, the bombing and gunnery ranges of the Nellis Air Force Base and in the northern and northwestern parts of Nevada (the Fallon zone).At present, all nuclear tests are carried out only at the NTS.	In the interests of the military forces, nuclear explosions were performed only at the North and the Semipalatinsk test sites. Also, during a field training exercise using nuclear weapons (on 14 September 1954, in the Orenburg region, a nuclear bomb was exploded at the altitude of 350 m.
What are the test site dimensions?	1350 square miles. Note (edit.): 3,650 km^2.	The test site is located on the Novaya Zemlya Islands (Fig. 2.) and is: 750 km long and 150 km wide, and occupies an area of 90 200 km^2, of which dry land comprises 55 000 km^2. Severny island is totally covered by glaciers, the Yuzhnyisland is mainly arctic tundra.
What was the capital cost of the facilities at the test site?	The net capital was equivalent to US $625 million	The basic cost of the test site (buildings, constructions, airdromes, moorages, communication systems etc.) was about 300 million roubles (in prices of 1984).

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
Are settlements at risk from the nuclear test programme?	No. The NTS is isolated from the west, north, and east by the property of the Nellis Air Force Base. All tests are carried out in the northern part of the NTS. The Amargosa valley is 30–50 miles away from the test areas, Biti - 30–40 miles, Glandale - 80–100 miles, Las-Vegas - 80–100 miles, Parump - 50–70 miles, Rachel - 40 miles, Tonopana - 70–100 miles.	No. Underground tests are carried out in the area of the Matochkin Shar straits, and the distance from there to the village of Anderma is about 300 km, to the town of Naryan-Mar - 440 km, to the cities of Vorkuta - 560 km, Murmansk - 900 km, Arkhangelsk - over 1000 km, Salekhard - 800 km, and to the town of Nadym - more than 1000 km.
How many nuclear tests are being conducted today at the test site?	In the last five years (1987–1991), on average, up to 13 tests per year.	only four tests were performed during the past five years (1987–1991): 1991 – 0, 1990 – 1, 1989 – 0, 1988 – 2, 1987 – 1. The uneven test conduct is due to the unilateral moratoria adopted in our country.
What is the cost of a nuclear test?	The cost of a nuclear test depends on its complexity: from several million to approximately 10 million dollars.	Depending on the type of the experiment implementation, its aims and purposes: on the average, 5 to 7 million roubles (in prices of 1984).
Are tests planned for special days or dates?	No. Usually the Department of Energy carries out tests on weekdays. Occasionally, weather conditions necessitate change to weekends or holidays.	No. Tests are carried out after completion of all preparatory measures, and the decisive factor is weather conditions.
Why did the USA and the USSR carry out the joint experiment?	The USA and the Soviet Union set off two explosions during the joint experiment, one at the NTS on 17 August 1988, and one on the Semipalatinsk test site on 14 September 1988 (13 September 1988 PDT). Both tests were a part of experimental work on the methods of monitoring the measurement of nuclear explosion yield, including monitoring by the Corrtex hydrodynamic method.	
How does the weather influence tests?	Tests are cancelled if weather forecasts show that wind may transport radioactivity to areas where it would exceed the prescribed radiation levels, and where such measures as staying indoors or evacuation are not possible.	Tests are cancelled if, according to weather forecasts, transfer of radioactive products in the direction of settlements would be possible in an emergency situation.

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
What kind of a wind velocities cause concern?	Strong winds decrease the margin of time for decay of radioactivity and may transport radioactive precipitation great distances. Therefore, the Department of Energy makes decisions on the basis of calculations of potential precipitation and radiation exposure due to this precipitation at the lee side. If the forecasts show that radiation exposure due to the precipitation would exceed the safety limits, and that no measures are possible to decrease it, the test is postponed. The average exposure dose of a body should not exceed 1.7 mSv over the entire US territory.	For the North Test Site the decisive factor is not the wind velocity, but its direction. However, in view of possible accidents, minimum wind velocity is preferable.
How often have radioactive releases occurred during nuclear tests?	Since 1971, there have been four insignificant releases. After the Riola tests in September 1980, a small leakage of radioactive gases occurred from the test borehole. After the Agrini explosion in March 1984, there was a leakage of noble gases with low radiation level during crater formation. After the Misty Rain test in April 1985, a small leakage of xenon-133 occurred during mine ventilation. After the Mighty Oak test in April 1986, a small leakage of xenon-133 was noted through a charcoal filter when workers were preparing the tunnel for access to the underground explosion zone. There was no danger to public health in any of these situations.	Measures taken with regard to the chosen location and depth of the charge, consideration of geological conditions, and methods for stemming the borehole exclude releases of radioactive products to the earth`s surface and the environment. At the same time, actually after 60% of underground nuclear tests, after some time insignificant amounts of inert radioactive gases leaked to the surface (radionuclides of krypton-85, -87, -88, and xenon-133, -135, 138). These leakages do not cause radioactive fallout and do not bring risks to participants in the tests and, moreover, to the population in the adjacent territories. At the test site territory (Fig. 1., zone B), only twice after underground nuclear explosions (on 14.10.69 and 02.08.87) were considerable amounts of gaseous radioactive explosion products recorded on the surface. As a consequence, additional measures to prevent releases of gases to the atmosphere were undertaken. The tests conducted in 1988–1990 confirmed their efficiency.

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
How dangerous can a significant release of radioactivity become to people outside the test site boundaries?	Tests are carried out only when the individual exposure dose outside the NTS would not exceed 5 mSv, even in the case of the worst release. 5 mSv is the standard established by the Government for radiation protection of population. However, taking into account varying degrees of sensitivity, for children this permissible dose was reduced to 1.7 mSv.	According to the standards of radiation safety NRB–76/87, the annual permissible exposure dose for direct participants in nuclear tests (category A personnel) should not exceed 50 mSv; for the personnel of military sub-units stationed at the test site, and persons attached to them (limited part of population, category B) – 5 mSv, which corresponds to recommendations of the International and National Commissions on Radiation Protection (ICRP, NCRP). These commissions have stipulated the permissible limit of individual exposure dose during life (70 years) at 0.35 Sv. According to calculations of experts, during a one year stay on Novaya Zemlya, one can receive a total dose of 1 mSv, which is five times lower than the permissible dose according to international standards. During the entire period of nuclear tests at Novaya Zemlya, this dose was not exceeded outside the test site in connection with the site's operation.
What is the significance of 5 mSv?	A typical X ray examination results in a dose of approximately 0.4 mSv. Exposure from natural background radiation varies from 1 to 2 mSv per year.	
Are people warned in cases of radioactive releases?	Yes. The officials of the states of Nevada, Utah and Arizona are notified immediately about any radioactive release into the atmosphere. Mass media are also notified.	Expert assessments for nuclear tests guarantee the safety of tests. However, a system has been developed for population notification about radiation danger in a case of an accident with release of radioactive products into the atmosphere.
Why it is necessary to continue nuclear weapon tests?	There are four principal reasons: (1) periodically checking weapons taken from stockpile in order to ascertain their degree of reliability; (2) testing new safety parameters in order to ensure the highest measure of weapon safety for the purpose of preventing accidental explosions or unauthorized use; (3) testing new weapon designs, e.g. lighter, smaller, more efficient, generating a smaller quantity of radioactive products; (4) examining the effect of radiation caused nuclear explosions on military equipment, such as communication facilities, electronics, missile warheads and other items.	

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
What is the influence of the Treaty on Limitation of Nuclear Tests?	The Treaty, signed by the USSR and the USA in Moscow on 5 August 1963, forbids nuclear tests in space, in the atmosphere and under water.	Conduct of nuclear weapons tests in the atmosphere can lead to an ecological catastrophe. Consequently, the Treaty of partial test ban in three media was a first international agreement to limit nuclear weapons. Practically, it did not limit attempts to improve nuclear arms. Yet it became a useful measure for protecting the environment and facilitated the conduct of negotiations on concluding other agreements, primarily the Treaty on Non-Proliferation of Nuclear Weapons (1968)
Why are some tests not announced?	The policy of not-announcing all nuclear tests was formulated in the USA when nuclear tests were renewed after the of 1958–1961 moratorium. Such policy gives right to the test officials to decide which tests should be declared, allowing for the technical criteria, and public health and safety aspects. All nuclear tests conducted prior to 5 August 1963 were announced.	In the USSR, conduct of nuclear tests had not been announced in mass media for technical reasons. Since the unilateral moratorium adopted by the USSR 06 August 1985–26 February 1987 on underground nuclear tests, the TASS [news agency], pursuant to a Government resolution, has been reporting all tests conducted. n.
What initiates the test designs and who makes the final decisions?	The designs are initiated by the US Ministry of Defence, by national laboratories and by the Department of Energy while the recommendations are forwarded to the President.	The test programmes have been compiled jointly by the Ministry of Defence and the MinAtom RF and have been considered and approved by the Government.
When were the last underground nuclear tests conducted?	In January 1992 Note (auth.): According to data from Russian monitoring of nuclear tests in the USA, the USA conducted two more nuclear tests in 1992: on 26 March and 30 April (as of 01 June 1992).	On 24 October 1990, at the North Test Site, and 19 October 1989, at the Semipalatinsk test site.
Are there areas with elevated radiation at the test site?		There are three exclusion zones on the test site territory, two of them are the consequence of aerial nuclear tests, and one is a result of an underground test carried out in 1987. The dose rates in these areas range from fractions to 1 mR/h.

Questions	Answers	
	Nevada Test Site (NTS) (answers by the USA experts)	**North Test Site** (answers by the RF experts)
How can one determine the dose received by a person in case of exposure?	Representatives from the areas surrounding the NTS carry dosimeters for measuring gamma radiation. The same dosimeters are also positioned in more than 100 locations beyond the test site. Recorders of the exposure levels operate in 22 communities and at ranches. Samples of air, water, milk and agricultural produce are also taken for analysis.	The radiation environment over the test site territory and adjacent regions are monitored constantly by hydrometeorological monitoring stations in the country and command posts of military units and by specialized subunits (units) of the Ministry of Defence. Furthemore, during the tests, in situ radiation monitoring is carried out directly both in the test area and on the territories of possible passage of air masses from the test region. It is carried out using specially equipped flying laboratories carrying highly sensitive measuring devices which make it possible to record an increment in the radioactive radiation dose rate over background values in units of μR/h,and equipment for sampling gas and aerosols for subsequent measurement of the radionuclide and chemical composition of substances in the atmospheric air. Subsequently, a number of scientific research institutes monitor the radionuclide content in the surface and deep soil layers and in lakes, rivers and groundwater.

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3. CHRONOLOGY AND RADIATION PHENOMENOLOGY OF UNDERGROUND NUCLEAR TESTS

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This section presents information about 39 underground nuclear tests carried out at the North Test Site in tunnels and boreholes. Figure 9 presents the chronology of underground nuclear tests. Information about the tests (Section 3.2) is given according to the unified scheme proposed by American experts: the test code name, the date of its conduct, the coordinator, basic conditions, and accompanying radiation consequences (phenomenology) [1]. In the text, terminology and concepts from *Glossary-81* [2] are used.

The underground nuclear tests conducted at the North Test Site are grouped according to the radiation situation they created:

— 15 explosions (36%) – radioactive products were localized in the massif almost completely (debris, gas containment);

— 25 explosions (60%) – were accompanied by seepage of radioactive inert gases (RNGs) into the atmosphere, without residual contamination;

— 2 explosions (4%) – were accompanied by gaseous and vaporized products entering the atmosphere under pressure, which characterizes these tests as non-standard (accidental) radiation situations for their direct participants (venting of radioactivity).

Not a single test was accompanied by radioactive fallout beyond the test site territory; i.e. the statute of the Moscow Treaty of 1963 (paragraph. 1 [B], Article 1) determining the conduct of underground nuclear tests was not violated. This was achieved by accurately following the design technological elements of the tests, including the choice of location for placement of the nuclear device (tunnel or borehole), with consideration, primarily, for the factors that determine guaranteed containment of gaseous explosion products underground. These factors include:

— the absence of geological ruptures, faults cracks near the explosion epicentre;

— minimum gas and moisture content of the rock;

— sufficient distance between the explosion chamber and locations of previous explosions;

— the absence of carbonate or carbon-containing rock in the zone of the explosion heat blast.

During the process of preparing the emplacement shaft for the nuclear device, visual observation and geophysical study of the massif were made using magnetometric, electric vertical probe, and seismic prospecting methods in order to construct a geological model from the point of location of the nuclear device to the surface.

If tectonic fault filled with components of high penetrability were found near the intended detonation chamber, it was moved far enough away to allow for the normalized depth ($\overline{H}$) for a nuclear explosion of not less than 90 m/kt$^{1/3}$ and since the late 1970s,more than 120 m/kt$^{1/3}$.

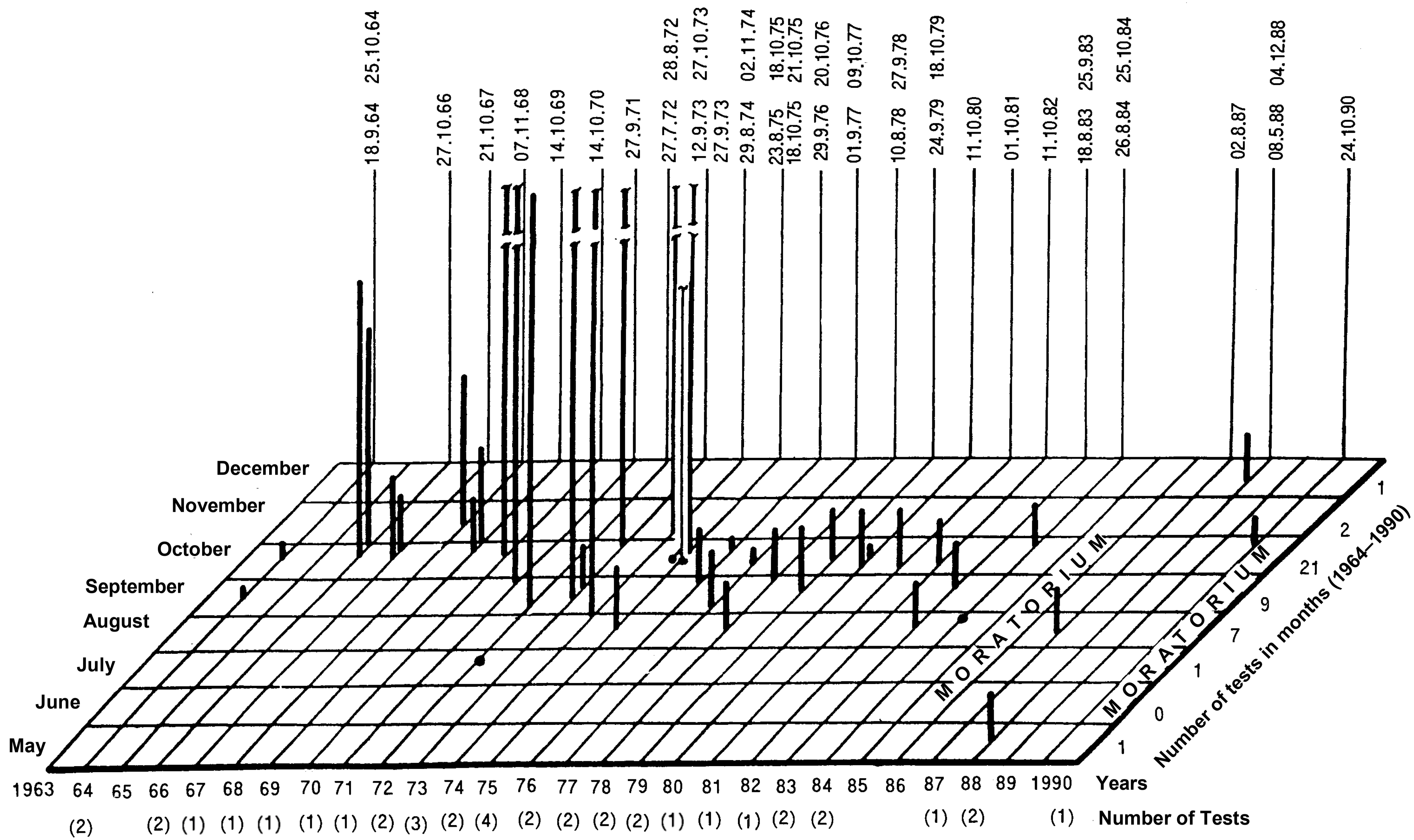

FIG. 9. Chronology of underground nuclear tests at the North Test Site (1964-1990).

To exclude releases of high-refractory explosion products into the atmosphere through the shaft, a stemming complex was built into it, with high-strength stemming elements and damping, gas-blocking, active precipitation of aerosols, and counterpressure components. The general algorithm for providing safety of a specific test includes the measures anticipated in its design, which are considered by:

- the interagency expert commission on assessing radiation and seismic safety at underground nuclear tests;
- the State commission on management of preparation and conduct of the tests;
- the designers, and subsequently specialists that implement a complex programme of remote diagnostic monitoring of the processes inside the shaft (measuring pressure, temperature of gases resulting from the explosion, radiation levels), and radiation measurements performed at and outside the test site using specialized ground, helicopter (in the test region), ship-, and aircraft-based radiation monitoring facilities in the areas adjacent to the test site, and within the 3–10-day transport of air from its territory.

It should be noted that the region of the Novaya Zemlya island is also regularly monitored by an international network for space, air, sea, and surface-based surveillance equipment and faciilities, including space satellites for optico-electronic and radiotechnical reconnaissance, reconnaissance aircraft of SR-71 and RC-135 types based on Norwegian territory, by the Norwegian reconnaissance vessel Maryata, and surface seismic and radiation environment monitoring stations in the Nordic countries. The equipment installed there permits detailed assessment of the consequences of nuclear tests for the environment of the Arctic regions.

Data on the radionuclide content in the environmental media are analysed in detail, in particular, by specialists of the Finnish Meteorological Institute, the Finnish Institute for Radiation and Nuclear Safety, and the National Laboratory in Riso (Denmark). For example, in August 1987, after an underground nuclear test on Novaya Zemlya, when a non-standard radiation situation arose, at least four Scandinavian countries used their national stations for monitoring the compliance with the 1963 Moscow Treaty demonstrated their extremely high sensitivity to gaseous radionuclides and radioiodine.

Reference

1. *The1963 Moscow Treaty on banning the nuclear weapons tests in three media, signed by the USSR, the USA and the UK imposes a ban on testing nuclear explosions of nuclear weapons and on any other nuclear explosions in the atmosphere, in space and underwater, and on nuclear explosions in any other media (i.e. also underground), "if such explosion causes radioactive fallout outside the territorial boundaries of the State under whose jurisdiction or control such explosion is conducted" (Article 1).*
2. *The Treaty does not contain a provision on international monitoring; and does not specify the use by the signatory States of the national technical means of verification available at their disposal. Nevertheless, the lack of special verification provisions in the treaty does not mean that there is no such verification in practice. It is carried out, and rather efficiently, with the help of the corresponding national means and facilities for radioactive product detection.*

In particular, since the 1963 Moscow Treaty became effective, reports have appeared from time to time about radioactive fallout beyond the territorial boundaries of the treaty member States after about underground nuclear blasts conducted on their territories which were sometimes accompanied by an escape of radioactive inert gases. Thus, it was reported that between 1963 and 1980, 40 cases of residual product fallout were recorded on Canadian territory as a result of underground nuclear test blasts conducted in the United States of

America. Mass media also reported on the radioactive fallout on the territory of the Scandinavian countries due to the underground nuclear tests carried out on 2 August 87 at the North Test Site.

At the same time, emphasis should be placed on the ambiguous interpretation of the criteria contained in Article 1 of the treaty which stipulates the conditions for carrying out underground nuclear explosions since it is presented differently in the English and Russian versions of the treaty. In particular, the English sentence on this criterion reads as follows: ″... if such an explosion causes the appearance of radioactive products (debris) beyond the boundaries of the territorial borders of the State...″; whereas the Russian text reads as follows: ″... if the explosion causes the fallout of radioactive precipitation (fallout) beyond the territorial boundaries of the State …". Hence, the general tendency of using the English text of the treaty and interpreting the aforesaid criterion in a more narrow sense compared to the Russian version. Yet since both texts of the treaty are authentic; only the limitations which the parties had in mind in signing the treaty can be used as the limitations presented in both texts.

3. *With regard to the foregoing, let us illustrate the likely interpretation of the term debris, which is the principal word in the English text of the treaty (based on an analysis by Stefan Marlon contained in report LASL-80-18 of July 1980)*

Since signing the treaty, The United States of America has attempted to carry out its nuclear weapons test programme in such a way so as to eliminate the escape of radioactive products, including radioactive gases, into the atmosphere from the test site. This approach attests to the concern about the state of their own environment and leads to safe underground nuclear tests in the spirit of the treaty. Nevertheless, the use of the term debris which denotes all radioactive products of nuclear blasts, including the gaseous fission products, is not a regular use of this word even for a native speaker of the English language. Consequently, its translation into the Russian language is very difficult. In its direct interpretation, this translation means fragments and fission products. The word fragment corresponds to the American use of fragment and debris while fission products corresponds to the English term fission fragments. In the Russian text of the treaty, the word sediment is used to translate the English words lees and dregs, which denote the residue after filtering a liquid. Consequently, the Russian text is specific with regard to the criterion of carrying out the nuclear blasts stipulated by the treaty, i.e., the explosions during which radioactive sediment does not fall out beyond the territorial boundaries of the State carrying out the test. According to this text, the escape of the radioactive gases which circulate in the atmosphere with disturbed currents in not a violation of the treaty. Consequently, according to the principle of authenticity, the meaning of debris must be identified with the concept of radioactive fallout and should not denote the escape of radioactive gaseous fission products.

3.1. CHRONOLOGY OF UNDERGROUND NUCLEAR EXPLOSIONS AT THE NORTH TEST SITE (1964–1990)

TABLE VIII

Nos.	Tests, date	Test conditions, number of nuclear changes (NC) in test, zone	Radiation consequences	
			Release of Radioactive products (RP)	Detection of RP
1	"G" 18.09.64	Tunnel, 1 NC, B	ICE: seepage of RNG	Onsite, RNG
2	"B" 25.10.64	Tunnel, 1 NC, B	ICE: seepage of RNG	Onsite, RNG
3	"A-1" 27.10.66	Tunnel, 1 NC, B	ICE: seepage of RNG	Offsite, RNG
4	"A-2" 27.10.66	Tunnel, 1 NC, B	ICE: seepage of RNG	Offsite, RNG
5	"A-4" 21.10.67 "A-5" 21.10.67	Tunnel, 1 NC, B Tunnel, 1 NC, B	ICE: seepage of RNG CCE (gas containment)	Onsite, RNG -
6	"A-3" 07.11.68	Tunnel, 3 NC, B	ICE: seepage of RNG	Onsite, RNG
7	"A-7" 14.10.69 "A-9" 14.10.69	Tunnel, 2 NC, B Tunnel, 1 NC, B	CCE (debris containment) ICE: venting of vapor and gas (RNG) in the EEZ in 1 hour after the explosion– non-standard radiation situation)	- Offsite, RNG
8	"A-6" 14.10.70	Tunnel, 3 NC, B	ICE: seepage of RNG	Offsite, RNG
9	"A-8" 27.09.71	Tunnel, 4 NC, B	ICE: seepage of RNG	Offsite, RNG
10	"Yu-3" 27.07.72	Borehole, 1 NC, A	CCE (debris containment)	-
11	"A-16" 28.08.72	Tunnel, 4 NC, B	ICE: seepage of RNG	Offsite, RNG
12	"V-1" 12.09.73	Tunnel-shaft , 4 NC, B	ICE: seepage of RNG	Offsite, RNG
13	"Yu-4" 27.09.73	Borehole, 1 NC, A	ICE: seepage of RNG	Onsite, RNG
14	"Yu-1" 27.10.73	Borehole, 1 NC, A	CCE (gases containment)	-
15	"A-11" 29.08.74	Tunnel, 5 NC, B	ICE: seepage of RNG	Offsite, RNG
16	"Yu-5N" 02.11.74	Borehole, 1 NC, A	CCE (gases containment)	-
17	"A-10" 23.08.75	Tunnel, 8 NC, B	ICE: seepage of RNG	Onsite, RNG
18	"Yu-6N" 18.10.75	Borehole, 2 NC, A	ICE: seepage of RNG	Onsite, RNG
19	"Yu-7" 18.10.75	Borehole, 1 NC, A	CCE (gases containment)	-
20	"A-12" 21.10.75	Tunnel, 5 NC, B	ICE: seepage of RNG	Offsite, RNG
21	"A-14" 29.09.76	Tunnel, 2 NC, B	ICE: seepage of RNG	Offsite, RNG
22	"A-15" 20.10.76	Tunnel, 4 NC, B	CCE (gases containment)	-
23	"A-17" 01.09.77	Tunnel, 4 NC, B	CCE (gases containment)	-
24	"A-7R*" 09.10.77	Tunnel, 1 NC, B	ICE: seepage of RNG	Offsite, RNG
25	"A-18" 10.08.78	Tunnel, 6 NC, B	ICE: seepage of RNG	Onsite, RNG
26	"A-19" 27.09.78	Tunnel, 7 NC, B	CCE (gases containment)	-
27	"A-32" 24.09.79	Tunnel, 3 NC, B	ICE: seepage of RNG	Onsite, RNG
28	"A-20" 18.10.79	Tunnel, 4 NC, B	ICE: seepage of RNG	Onsite, RNG
29 29	"A-25" 11.10.80 "A-30" 11.10.80	Tunnel, 4 NC, B Tunnel, 3 NC, B	CCE (debris containment) ICE: seepage of RNG	- Offsite, RNG
30	"A-23" 01.10.81	Tunnel, 4 NC, B	CCE (gases containment)	-
31	"A-37" 11.10.82	Tunnel, 4 NC, B	ICE: seepage of RNG	Onsite, RNG
32	"A-40" 18.08.83	Tunnel, 5 NC, B	ICE: seepage of RNG	Onsite, RNG
33	"A-21" 25.09.83	Tunnel, 4 NC, B	ICE: seepage of RNG	Onsite, RNG
34	"A-100" 26.08.84	Tunnel, 1 NC, B	CCE (debris containment)	-
35	"A-26" 25.10.84	Tunnel, 4 NC, B	ICE: seepage of RNG	Offsite, RNG
36	"A-37A" 02.08.87	Tunnel, 5 NC, B	ICE: early release of gaseous and vaporized products through the tunnel and along the fault crack on the mountain slope (venting of radioactivity) – non-standard radiation situation	Offsite, RNG
37	"A-24" 08.05.88	Tunnel, 3 NC, B	ICE: seepage of RNG	Onsite, RNG
38	"A-27" 04.12.88	Tunnel, 5 NC, B	CCE (gases containment)	-
39	"A-13N" 24.10.90	Tunnel, 8 NC, B	CCE (gases containment)	-

"A-7R* -repeated test in the tunnel A-7

3.2. RADIATION PHENOMENOLOGY OF UNDERGROUND NUCLEAR TESTS AT THE NORTH TEST SITE

Test:	**G**
Date:	18.09.64
Coordinator:	VNIITF (All-Union Scientific Research Institute of Experimental Physics)
Location:	Zone B
Method:	In a tunnel, $\overline{H}$ ~ 100 m/kt$^{1/3}$ (a low-yield explosion)
Products released:	ICE (low-intensity seepage of RNG)

Low intensity seepage of RNG in the EEZ began within the first 10 minutes after the explosion. There was no radioactive fallout. The total amount of RNG that entered the atmosphere along cracks in the rock massif was approximately $1.4 \cdot 10^{14}$ Bq. In the RNG jet radionuclides of krypton and xenon were identified over the test site, spreading mainly to the south.

In the technological site zone, the EDR did not exceed 2 R/hour, and 30 km beyond zone B in the near-surface atmospheric layer, no excess of EDR above the background value was recorded by means of field dosimetric reconnaissance and radiation monitoring.

Summary

No release of RNG in detectable amounts beyond the test site area occurred. The radiation situation was standard and corresponded to the forecast.

Test:	**B**
Date	25.10.64
Coordinator:	VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 200 m/kt$^{1/3}$(a low-power explosion)
Products detected:	Offsite, RNG
Products released:	incomplete contained explosion (ICE) (low-intensity seepage of RNG)

Seepage of RNG in the EEZ began relatively late, after approximately 40 minutes, and was insignificant. No radioactive fallout occurred. The total amount of RNG that entered the atmosphere along cracks in the massif was approximately $3.7 \cdot 10^{16}$ Bq. In the RNG jet, radionuclides of krypton and xenon were identified over the test site, spreading mainly to the south.

In the zone of the technological site, the EDR did not exceed 1.5 R/hour, and 85 km outside zone B in the near-surface atmospheric layer, no excess of EDR above the background value was recorded by means of field dosimetric reconnaissance and radiation monitoring.

Summary

No release of RNG in detectable amounts outside the test site area occurred. The radiation situation was standard and corresponded to the forecast.

Tests:	**A-1 and A-2**
Date	27.10.66
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 90 m/kt$^{1/3}$ (megaton-class test)
Products detected:	Offsite, RNGRNG
Products released:	ICE (low-intensity seepage of RNG)

Seepage of RNGRNG in the EEZ began during the first 15 minutes after the explosion. No radioactive fallout occurred. The total amount of RNG that entered the atmosphere along cracks in the massif was approximately $3.7 \cdot 10^{17}$ Bq. In the RNG jet, radionuclides of krypton and xenon were identified, spreading in three days to the east, mainly along the Matochkin Shar strait towards the Kara Sea, where they were scattered by a general transport of air masses in a southeasterly direction. In the zone of the technological site, the EDR reached 7 R/hour for a short time.

Summary On the whole, the radiation situation was regular and consistent with the forecast.

Reference

With regard to this test, the USA and the USSR exchanged statements pursuant to the provisions of the 1963 Moscow Treaty. In particular, on 12 November 1966, the USA made an inquiry which indicated that "... the USA collected beyond the USSR boundaries radioactive particles directly related to the nuclear explosion of 27 October 1966". In this connection, the US Government would welcome an attempt by the USSR Government to present any information related to this case. For its part,, the USSR made a clarification from which it followed that on 27 October 1966 in the arctic areas of the USSR an underground nuclear explosion was detonated at a great depth in conditions that eliminated the appearance of radioactive particles in the atmosphere and radioactive fallout. The special monitoring bodies observing the radiation situation have confirmed that the nuclear explosion was detonated without any release of radioactive particles to the surface or radioactive fallout. Therefore, the test carried out in the USSR on 27 October 1966 fully meets the provisions of the Moscow Treaty.

Tests:	**A-4 and A-5**
Date	21.10.67
Coordinators:	VNIIEF (A-4) and VNIITF (A-5)
Place	Zone B
Method	In a tunnel, $\overline{H}_{A\text{-}4}$ ~ 90 m/kt$^{1/3}$, $\overline{H}_{A\text{-}5}$ ~ 120 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	A-4: ICE (low-intensity seepage of RNG into the epicentral zone from A-4); A-5: CCE (gas containment)

The seepage of RNG in the EEZ of the A-4 tunnel began at least 20 minutes after the explosion. No radioactive fallout occurred. Data about the total amount of RNG that entered the atmosphere in the form of krypton and xenon radionuclides are absent. On the next day, RNGs were not detectable either in the area of EEZ or along the air mass propagation path.. The total amount of secondary ^{137}Cs deposited on the surface in the test zone did not exceed $3.7 \cdot 10^{11}$ Bq.

In the zone of the technological site, the EDR briefly reached 10 R/hour.

Summary

At the A-4 test, the radiation situation was regular and consistent with the forecast. At the A-5 test, no release of gaseous radioactive products occurred into the atmosphere.

Reference

No claim was made pursuant to the 1963 Moscow Treaty.

Test:	**A-3**
Date	07.11.68
Coordinator:	VNIITF
Place	Zone B
Method	In an tunnel, $\overline{H}$ ~ 140 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (very late low-intensity seepage of RNG)

Low intensity seepage of RNG in the atmosphere began at least one hour after the explosion, and the process was a low-intensity one since the gases ejected into the tunnel were filtering through the tectonic crack in the rock mass broken up by the explosion

The total amount of RNG that entered the atmosphere did not exceed $3.7 \cdot 10^{14}$ Bq. Area contamination with secondary strontium-90 and caesium-137 was practically absent. RNGs were detected only in the zone of the technological site, where the EDR briefly reached 5 R/hour.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

No claim was made pursuant to the 1963 Moscow Treaty.

Tests:	**A-7 and A-9**
Date	14.10.69
Coordinators:	VNIIEF and VNIITF
Place	Zone B
Method	In an tunnel, $\overline{H}_{A\text{-}7}$ ~ 120 m/kt$^{1/3}$, $\overline{H}_{A\text{-}9}$ ~ 100 m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	A-7: CCE (debris containment); A-9: Escaped of gas and vapour mixture on the EEZ, ICE (venting of radioactivity)

l. Approximately 60 minutes after the detonation, the vapour and gas mixture was suddenly vented along the tectonic track formed during the thawing of the infiltrated moisture ‘lens’ along the permafrost stratum into the epicentral explosion zone from the A-9 tunnel.

In the ‘cloud’, radionuclides of krypton, xenon, iodine, and tritium, strontium-89, caesium-137, -138 were detected. Due to the calm weather conditions, radioactive products ‘hovered’ over the technological site, causing an EDR of up to some hundreds R/hour. This called for immediate evacuation of personnel to a safe zone. Approximately 12 hours after the explosion, the staff were returned to continue the basic operations, while adhering to radiation safety requirements. On the third day, there was a slow drift of radioactive products from zone B to the north-northwest to the Barents sea, where they could still be detected three days later at a distance of up to 500 km.

Summary

The A-7 test was not accompanied by release of radioactive products of explosion origin into the atmosphere. At the A-9 test, the dynamic release of radioactive products to the earth`s surface determined an accidental (non-standard) radiation situation. This called for the evacuation of direct participants in the test, who nevertheless were exposed above the levels established for the category A personnel, and some required subsequent preventive hospitalization..

Reference

No claim was made pursuant to the 1963 Moscow Treaty.

Test:	**A-6**
Date	14.10.70
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 90 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

Seepage of RNG in the EEZ began at least 10–15 minutes after the explosion. The total amount of RNG that entered the atmosphere was $7.4 \cdot 10^{16}$ Bq. In the RNG jet, radionuclides of krypton, xenon, iodine (traces), strontium-89 and caesium-137 were identified. The total amount of secondary caesium-137 which fell out within the territory of the test site is estimated as $(1.5\text{-}1.8) \cdot 10^{13}$ Bq. In the zone of the technological site, the EDR reached 250 R/h; at a distance of 10 km it was no more than 5 mR/h (measurements on the surface).

The general RNG spreading direction during the first day was south, along the central and the eastern parts of the south island of Novaya Zemlya archipelago (towards Galla cape), and further on to the southwest in the area of Mezhdusharskiy island, then to the south and southwest (60 km to the east of the Kolguev Island), and next to the north of the town of Naryan-Mar, where the EDR reached 0.3 mR/h at the RNG jet altitude (700–1,800 m). Subsequently, the jet turned northward to the region of the Yamal peninsula and Belyi island. There was no radioactive fallout beyond the test site boundary

Summary

On the whole, the radiation situation was regular and predictable allowing for the actual weather conditions.

Reference

With regard to these tests, the following exchange took place between the USSR and the USA under the provisions of the 1963 Moscow Treaty In particular, the USA issued a memorandum on 6 January 1971, which stated that "... the USA collected radioactive material beyond the USSR boundaries directly related to the nuclear explosion on 14 October 1970". The USSR, in turn, stated that "... efficient safety measures were taken during the explosion as result of which there was no radioactive fallout".

Test:	**A-8**
Date	27.09.71
Coordinators:	VNIITF and VNIIEF
Place	Zone B
Method	In an tunnel, $\overline{H}$ > 90 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

Seepage of RNG into the EEZ began 15–20 minutes after the explosion. No radioactive fallout occurred. In the RNG jet, radionuclides of krypton, xenon, iodine (traces), strontium-89, and caesium-137 were detected. Assessments give the value of about $5.6 \cdot 10^{11}$ Bq of secondary caesium-137 deposited in the test area. In the zone of the technological site, the EDR did not exceed 1 R/h. The principal transport of the RNG jet occurred during two days towards the northwesterly part of the Kara sea, further to the east of Dikson island.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

With regard to this test, the following exchange took place between the USA and the USSR under the provisions of the 1963 Moscow Treaty. Thus, the USA sent a memorandum on 16 December 1971, which indicated that "... the USA collected radioactive material beyond the USSR's boundaries directly related to the nuclear explosion in the USSR on 27 September 1971. Mindful of the provisions of paragraph 1[B] of the Article 1 of the Treaty banning nuclear weapons tests in the atmosphere, in space and underwater, the USA wished to draw the Soviet Government`s attention to this issue and to the importance of taking proper care so as to ensure compliance with said Treaty. The USA treats this case as causing deep concern due to the fact that a relatively large quantity of radioactive substances has been collected beyond the territory of the USSR. The US Government would welcome an attempt by the USSR Government to provide any relevant information pertaining to this incident and with regard to the increasing frequency of these types of phenomena ...".

The USSR gave the following answer on 10 January 1972: "On 27 September 1971, an underground nuclear explosion was conducted in the USSR, which was accompanied by insignificant seepage of gaseous products into the atmosphere. This explosion, as all the previous ones, was conducted under conditions which eliminate the escape of radioactive explosion products in the form of aerosols beyond the USSR boundaries. The relevant Soviet bodies have taken and are continuing to take all the necessary measures for strictly adhering to the 1963 Moscow Treaty under which nuclear explosions causing radioactive fallout beyond national boundaries are banned ...".

The Soviet side once again drew the attention of the American side to the fact that during the conduct of the underground nuclear explosion Diagonal Line in the USA on 24 November 1971, seepage of radioactive products into the atmosphere did indeed occur in the form of aerosol effluent. However, the USSR inquiry of 30 November 1971 about this event elicited no official estimates or explanations in the light of the 1963 Moscow Treaty.

Test:	**Yu-3**
Date	27.07.72
Coordinator:	VNIITF
Place	Zone A
Method	In a borehole, $\overline{H}$ > 400 m/kt$^{1/3}$
Products detected:	None
Products released:	CCE (debris containment)

Summary

The test is characterized as the explosion of complete internal action, virtually without seepage of RNG into the atmosphere.

Reference

No claim was made pursuant to the 1963 Moscow Treaty.

Test:	**A-16**
Date	28.08.72
Coordinator:	VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 90 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

Seepage of RNG into the atmosphere began in the EEZ approximately 10 minutes after the explosion (principal seepage), and from the portal (entrance) tunnel approximately 30 minutes after the explosion. The total amount of RNG entering the atmosphere was approximately $3.7 \cdot 10^{16}$ Bq. Secondary caesium-137 whose amount in the test zone was equal to approximately $1.8 \cdot 10^{13}$ Bq was detected. In the zone of the technological site, the EDR reached 100 R/h. Seven hours later, the RNGs were transported to the Kara sea in a certain transport sector specific to this test, where they were scattered. Radiation monitoring of the gas transport was conducted as far as the Taimyr peninsula for four days.

Summary

On the whole, the radiation situation was regular and, allowing for the real weather conditions, corresponded to the forecast for the megaton class test.

Reference

In connection with this test, on 11 January 1973 the USA announced that it had collected radioactive products outside USSR boundaries… As with the preceding cases, the Soviet side gave relevant explanations, which read that "... the explosion was detonated under conditions which eliminated the escape of radioactive products in the form of fallout beyond the territory of the USSR."

Test:	**V-1**
Date	12.09.73
Coordinators:	VNIITF and VNIIEF
Place	Zone A
Method	In a tunnel-shaft, $\overline{H}$ ~ 95 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

The seepage of RNG in the EEZ began 10–12 minutes after the explosion. The total amount of secondary caesium-137 deposited in the test zone was assessed as approximately $5.6 \cdot 10^{11}$ Bq. The maximum dose rate in the RNG jet above the EEZ three hours later was 2.2 R/hour. Approximately five hours later, the upper part of the jet (above one km) was transported toward the Kara Sea, subsequently spreading in a southeasterly direction. The lower part of the jet spread over the archipelago in a southerly direction. The most remote location of RNG detection by means of precision measurement facilities of airborne monitoring was in the region of the city of Izhevsk.

Summary

On the whole, the radiation situation was regular and consistent with the forecast for the megaton class test.

Reference

With regard to this test, the following memorandum was received from the USA on 21 March 1974 indicating that the radioactive explosion products were detected beyond the territory of the USSR. , The USSR gave a relevant explanation on 21 May 1974 with regard to the fact that this nuclear explosion was conducted while adhering to conditions that eliminated radioactive fallout.

Test:	**Yu-4**
Date	27.09.73
Coordinator:	VNIITF
Place	Zone A
Method	In a borehole, $\overline{H}$ ~ 90 m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	ICE (low-intensity seepage of RNG)

There was a low-intensity seepage of RNG with precepitation of secondary caesium-137 in the test zone occurred in an amount no exceeding $3.7 \cdot 10^{11}$ Bq. The RNG jet spread predominantlyover the test site territory in a southeasterly direction, then turned northward.

Summary

On the whole, the radiation situation was regular and consistentwith the forecast.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**Yu-1**
Date	27.10.73
Coordinator:	VNIIEF
Place	Zone A
Method	In a borehole, $\overline{H}$ ~ 120 m/kt$^{1/3}$ (a megaton class test)
Products detected:	None
Products released:	CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually , without RNG seepage into the atmosphere.

Reference

Despite that fact, a protest was launched by the US side on 22 March 1974 under the 1963 Moscow Treaty which attested that there were objective technical difficulties in identifying the radioactivity sources.

Test:	**A-11**
Date	29.08.74
Coordinators:	VNIIEF and VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 120 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

The seepage of RNG into the atmosphere began 10–15 minutes after the explosion and occurred through the tunnel. There was probably also a seepage of RNG in the epicentral explosion zone. There was no radioactive fallout. The total amount of RNG entering the atmosphere was equal to approximately $1.8 \cdot 10^{14}$ Bq. At the tunnel mouth, The EDR at site near portal of tunnel did not exceed 3 R/h. Three days later, RNGs were detected beyond the test site boundaries above the Kara sea in the direction of the Yamal peninsula. The gas spread over the Kamenny cape subsequently turning to the northeast.

Summary

On the whole, the radiation situation was regular and consistent with the forecast for a megaton class test.

Test:	**Yu-5N**
Date	02.11.74
Coordinator:	VNIITF
Place	Zone A
Method	In a borehole, $\overline{H}$ ~ 120 m/kt$^{1/3}$ (megaton class test)
Products detected:	None
Products released:	CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually without RNG seepage into the atmosphere.

Reference

With regard to the A-11 and Yu-5N tests, the USA lodged a protest pursuant to the 1963 Moscow Treaty regarding the alleged radioactive fallout beyond USSR territory…. On the basis of the results of the corresponding radiation monitoring, which detected the presence of radioactive gases in the atmosphere only after the A-11 test, necessary clarification was given to the American side which confirmed that the provisions of the 1963 Moscow Treaty had been adhered to.

Test:	**A-10**
Date	23.08.75
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 90 m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	ICE (late low-intensity seepage of RNG)

The seepage of RNG into the atmosphere began with considerable delay (approximately after 50 minutes) and was insignificant. The EDR at the portal tunnel site did not exceed 1.5 R/h.. No RNGs were detected beyond the test site territory.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Test:	**Yu-6N, Yu-7**
Date	18.10.75
Coordinator:	VNIITF
Place	Zone A
Method	In a borehole, $\overline{H}$ ~ 110-120 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Onsite, RNG
Products released:	Yu-6N: ICE (late seepage of RNG); Yu-7: CCE (gas containment)

The seepage of RNG in the EEZ during the Yu-6N borehole started at least 30 minutes after the explosion and was insignificant. The maximum EDR value in the actual technological site zone was equal to approximately 0.4 R/h..

The Yu-7 test is characterized as a fully contained explosion, virtually without seepage of RNG into the atmosphere.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Test:	**A-12**
Date	21.10.75
Coordinators:	VNIITF and VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 90 m/kt$^{1/3}$ (a megaton class test)
Products detected:	Offsite, RNG
Products released:	ICE (early seepage of RNG)

The seepage of RNG into the atmosphere began in the EEZ approximately 10 minutes after the explosion. The total amount of RNG entering the atmosphere was equal to approximately $1.1 \cdot 10^{16}$ Bq, and caused precipitation of up to $2.2 \cdot 10^{12}$ Bq of secondary caesium-137 within the test site. The maximum EDR value in the actual technological site was equal to 250 R/hour. The RNG spread predominantly in a southerly direction on the next day in the area of Vaygach island, and then to the southwest of Amderma village. On the fourth day, the head portion of the jet was detected at an altitude of 700–1500m in the foothills of the Urals ridge to the south of the town of Pechora.

Summary

On the whole, the radiation situation was regular and consistent with the forecast for a megaton class test.

Reference

A statement was received from the US State Department on 23 December 1975 That radioactive particles attributed to all three tests conducted in Novaya Zemlya in 1975 (A-10, Yu-6N, and A-12) were detected beyond the USSR boundaries. In response, the Soviet side noted that these claims were unfounded since radioactive fallout had not occurred during either of these tests beyond the test site boundaries.

Test:	**A-14**
Date	29.09.76
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 95 m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	ICE (low-intensity seepage of RNG)

The seepage of RNG occurred at the EEZ no earlier than 10 minutes after the explosion, but had low intensity, and caused precipitation in the near zone no more than $3.7 \cdot 10^{11}$ Bq of secondary caesium-137. The maximum EDR value at the actual technological site reached 3 R/h.

Beyond the test site boundaries, RNG was detected over the Kara sea at a distance of 400 km (with operative airborne radiation monitoring up to the region of Khanty-Mansiysk – Turukhansk).

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Test:	**A-15**
Date	20.10.76
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H} \sim 140$ m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually without seepage RNG into the atmosphere.

Test:	**A-17**
Date	01.09.77
Coordinators:	VNIIEF and VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H} \sim 150$ m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually without seepage of RNG into the atmosphere.

Reference

The USA sent a memorandum on November 1977, which indicated that "… the USA collected beyond USSR territorial boundaries radioactive precipitation directly attributable to the nuclear explosion on September 1977." The note also emphasized that ″pursuant to paragraph 1 (b) of Article 1 of the 1963 Moscow Treaty, the US Government wished to draw the attention of the Soviet Government to this incident and also to the importance of proper precautions necessary for adherence to this Treaty. In so doing, the US Government implying that the Soviet Government recently confirmed its adherence to the objectives and principles of this treaty as it applied to the treaty on limiting underground nuclear weapon tests and to the treaty on underground PNE."

In our opinion, it should be stated with regard to the foregoing that the technical difficulties of identifying the radioactivity sources exist in monitoring the 1963 Moscow Treaty. However, these have been. overcome after an exchange of relevant information about tests.

Test:	A-7P
Date	09.10.77
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 100 m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	ICE (seepage of RNG into the atmosphere through the portal tunnel)

The seepage of RNG occurred through the portal tunnel, and began rather early (several minutes after the explosion) since the test was carried out for the second time in the same tunnel (repeat use). The maximum EDR value near portal tunnel was equal to 10^3 R/h.. The total characteristics of the seepage: the amounts of precipitation of secondary strontium-89 and caesium-137 was $1.3 \cdot 10^{13}$ Bq and $1.5 \cdot 10^{12}$ Bq, respectively. Iodine radionuclides (iodine-131 – about $1.1 \cdot 10^{14}$ Bq) were also detected. The RNG jet spread over the Matochkin Shar straits, and the Kara sea in the southeast, and then to the area of the town of Salekhard. Continuous airborne radiation monitoring of this propagation was carried out all the way to the Ob`Bay for three days.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	A-18
Date	10.08.78
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 110 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG through the tunnel)

The seepage of RNG occurred in the EEZ approximately 10 minutes after the explosion and through the tunnel portal after approximately seven minutes, which determined the maximum EDR value at the tunnel portal site of up to 10 R/h.. The amount of secondary caesium-137 deposited in the test area did not exceed $2.6 \cdot 10^{12}$ Bq.

The RNG jet spread predominantly in a southeasterly direction with a subsequent turn over the Kara sea in the northeast.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-19**
Date	27.09.78
Coordinator:	VNIIEF
Place	Zone B
Method	In an tunnel, $\overline{H}$ ~ 100 m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually without the seepage RNG into the atmosphere.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-32**
Date	24.09.79
Coordinator:	VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 120 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

The seepage of RNG occurred in the EEZ approximately 10 minutes after the explosion. The maximum EDR value in the tunnel portal site was equal to 300 R/h. The amount of secondary strontium-89 and caesium-137 precipitation in the test zone was equal to approximately $5.2 \cdot 10^{12}$ Bq and $1.1 \cdot 10^{12}$ Bq, respectively.

Calm weather prevailed in the test zone. As a result, RNG spread in one day to the Mityushikha bay, and later to the north along the coast of Novaya Zemlya without outcome beyond the test site area.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-20**
Date	18.10.79
Coordinator:	VNIIEF
Place	Zone B
Method	In an tunnel, $\overline{H}$ ~ 120 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

The seepage of RNG primarily through the EEZ began approximately 10 minutes after the explosion, and resulted a maximum EDR value in the area of the technological site of up to 1.5 R/h.. The amount of secondary caesium-137 precipitation did not not exceed $1.5 \cdot 10^{12}$ Bq.

RNG spread predominantly in a southeasterly direction over the test site territory without leaving its bounds.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Test:	**A-25, A-30**
Date	11.10.80
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}_{A\text{-}25} \sim 120$ m/kt$^{1/3}$; $\overline{H}_{A\text{-}30} \sim 140$ m/kt$^{1/3}$
Products detected:	Offsite, RNG
Products released:	A-25: None, CCE (debris containment): A-30: ICE (seepage of RNG)

The A-25 test is characterized as a fully contained explosion virtually without RNG seepage into the atmosphere.

The A-30 test was accompanied by low-intensity seepage of RNG, which began approximately 10 minutes after the explosion though the EEZ and approximately 20 minutes in the tunnel portal which resulted in a secondary caesium-137 fallout in an amount not exceeding $1.8 \cdot 10^{11}$ Bq. The maximum EDR value in the area of the tunnel portal reached 8 R/h.. RNG spread predominantly over the Matochkin Shar strait over the Kara sea.

Summary

On the whole, the radiation situation was regular and consistent with the forecast.

Reference

No protest was lodged pursuant to the1963 Moscow Treaty.

Test:	**A-23**
Date	01.10.81
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H} > 120$ m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

Summary

The test is characterized as a fully contained explosion virtually without RNG seepage into the atmosphere.

Reference

In a memorandum of 16 December 1981 by the USA, attention was drawn to precipitation which could be directly attributed to the nuclear explosion conducted on 1 October 1981." It was underlined that the US Government was of the opinion that adherence to the provisions of the 1963 Moscow Treaty by all parties was vitally important for preserving the integrity and effectiveness of this treaty and developing trust between the USA and the USSR necessary for ensuring success of future negotiations on arms limitation. With regard to the foregoing, the US Government requested that the Government of the Soviet Union provide data pertaining to that test.

In response to this statement, the Soviet side gave the corresponding clarifications on 18 December 1981, and indicated that the USSR was a firm supporter of adherence to the treaty banning nuclear weapon tests in three media, and had not undertaken — nor was undertaking — any deliberate actions aimed at departing in any way from strict adherence to the treaty provisions.

Test:	**A-37**
Date	11.10.82
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H} > 120$ m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

The seepage of RNG began in the EEZ approximately 12 minutes after the explosion.

The total amount of RNG entering the atmosphere was equal to approximately $3.7 \cdot 10^{13}$ Bq.

The maximum EDR at the actual technological site was equal to 0.25 R/h. There was no escape of RNG beyond the test site boundaries.

Summary

On the whole, the radiation situation was regular and consistent with the prediction. .

Test:	**A-40**
Date	18.08.83
Coordinators:	VNIIEF and VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H} >> 120$ m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

Summary

The seepage of RNG began in the EEZ no sooner than 10 minutes after the explosion and led to precipitation of secondary caesium-137 in an amount no more than $7.4 \cdot 10^{10}$ Bq. There was no seepage of RNG beyond the test site boundaries.

Test:	**A-21**
Date	25.09.83
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ > 120 m/kt$^{1/3}$
Products detected:	On-site, RNG
Products released:	ICE (seepage of RNG)

Summary

The seepage of RNG began no sooner than 15 minutes after the explosion and was responsible for secondary caesium-137 precipitation not exceeding $1.5 \cdot 10^{11}$ Bq. There was no seepage of RNG beyond the test site area boundaries.

Reference

Despite this fact, the Deputy Director of the US Arms Control and Disarmament Agency delivered a memorandum to a counsellor at the USSR embassy in Washington on 15 November 1983 which drew the attention of the USSR Government to the fact that "... the USA Government had collected beyond the USSR boundaries radioactive precipitation directly attributed to the nuclear explosions conducted on 18 August 1983 and 25 September 1983," and that these incidents occurred despite earlier assurances made by the USSR Government that it was taking all necessary measures to ensure that such incidents would not happen in the future. Attention was also drawn to the fact that, as a result of this, a question arose as to whether there was complete understanding of the concern expressed by the US Government in this regard, and whether the USSR Government intended to take additional measures to prevent the appearance of radioactive fallout in the atmosphere beyond the territorial boundaries of the country. Consequently, the Government of the Soviet Union provided the information pertaining to the aforementioned incidents.

Naturally, in response to this statement, the Soviet side gave the necessary clarifications, which confirmed the absence of radioactive fallout due to the aforesaid test.

Test:	**A-100**
Date	26.08.84
Coordinator:	VNIIEF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 110 m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (debris containment)

Summary

The test is characterized as a fully contained explosion virtually without RNG seepage into the atmosphere.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-26**
Date	25.10.84
Coordinator:	VNIITF
Place	Zone B
Method	In a tunnel, $\overline{H}$ ~ 115 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

The seepage of RNG began in the EEZ and at the tunnel portal in the first minutes after the explosion. The total amount of RNG entering the atmosphere was equal to approximately $4 \cdot 10^{16}$ Bq. The amounts of secondary strontium-89 and caesium-137 fallout in the near zone were about $7.4 \cdot 10^{12}$ Bq and $1.1 \cdot 10^{11}$ Bq, respectively. The maximum EDR value on the technological site was 500 R/h. The RNG spread beyond the test site in several hours after the explosion over of the Kara sea, and further to the region of the town of Surgut.

Summary

The radiation situation in the test area was fairly stressed for the test participants, and hindered the performance of subsequent technological operations.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-37A**
Date	02.08.87
Coordinator:	VNIITF
Place	Zone B
Purpose:	Nuclear weapon development or perfection
Method	In a tunnel, $\overline{H}$ ~ 95 m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE, early release of gaseous and vapour debris (venting of radioactivity)

In approximately 1.5 minutes after the explosion, a release of vapour and gaseous mixture occurred along a crack of natural fracture of partially melted glacier on the slope of the mountain along the tunnel axis, attributed to high-temperature and high- pressure explosion products entering the tunnel. In the atmosphere, besides the RNG mixture, radionuclides of barium, iodine, caesium, strontium, antimonium, tellurium etc. also entered.

Due to calm weather conditions for six days, the radioactive products "hung" above the technological site, causing the EDR in the monitoring points above 500 R/h.. An accidental situation arose, which required immediate evacuation of personnel to safe areas.

Radioactive products slowly moved out of zone B, not reaching the Cape of Stolobvoy, and in the south and southeast directions to Gribovaya bay and the Maloye Pukhovoye lake, where they remained for several days. On 7 August, i.e. in five days, radioactive products were detected in the area of Abrosimova bay. The plane-laboratory of radiation monitoring on 5–7 August detected no radioactive products in the region of the Kola peninsula. Later, on 7–8 August, in connection with transport of the anticyclone in the direction of Spitsbergen, the wind in the region of Novaya Zemlya changed to the northeast and, south of the Barents sea, to the east and southeast. Therefore, the radioactive products remaining in the region of Novaya Zemlya, beginning from 8 August, could move along the southeast periphery of the anticyclone to the Kola Peninsula and to the north of Scandinavia. The reverse trajectories from Sweden of 11 August plotted at the State Committee for Hydrometeorology confirm the possibility.

The amounts of strontium-89 and caesium-137 formed in the atmosphere were assessed as approximately $1.5 \cdot 10^{13}$ Bq and $1.8 \cdot 10^{11}$ Bq, respectively. The amount of iodine radionuclides that entering the atmosphere was about $3.7 \cdot 10^{13}$ Bq. Currently, the area of the A-37A tunnel is surrounded by a sanitary-protective zone (EDR is 50-60 μR/h., the maximum value under the tunnel portal is up to 0.5 mR/h.).

Summary

Dynamic escape of the explosion products to the earth`s surface created an emergency situation. This called for evacuation of the test participants, which ensured their safety. There was no radioactive fallout beyond the test site boundary in detectable quantities, except for trace amounts of radioiodine.

Reference

Nine days after the test, detection of an insignificant elevation of the radioactivity level was announced in Sweden and other Scandinavian countries, which led Western media to interpret this as a consequence of the Novaya Zemlya test. With regard to the foregoing, a briefing was conducted on the basis of actual data at the press centre of the USSR Ministry of Foreign Affairs in which journalists were informed about the situation which evolved in the aforementioned region after the underground nuclear test by Chairman of the USSR State Committee on Hydrometeorology and Environmental Monitoring Yu.A. Izrael, Chief of the Information Department of the USSR Ministry of Foreign Affairs G.I. Gerasimov, and Deputy Director of the Department of Peaceful Use of Nuclear Energy and Space at the USSR Ministry of Foreign Affairs B.G. Mayorskiy. In particular, they indicated that in this case, in stating that an increase in the radioactivity was allegedly due to the products from the underground nuclear explosion on Novaya Zemlya, no one noted that on 10 August, i.e. one day before the insignificant increase in radioactivity was detected in Sweden, an accident occurred at a nuclear power plant in Great Britain. They also pointed out the fact that between 2 and 7 August, a special laboratory aircraft patrolled along the border between Soviet Union and the Scandinavian countries, and did not detect the slightest increase in radioactivity, They also mentioned the fact that the radioactivity level in Sweden due to natural radon background is equal to 1–2 Bq/m^3; on 11 August, this level increased there by 1 mBq/m^3. The Scandinavian scientists themselves are of the opinion that this is not worth mentioning since insignificant amounts of radioactivity can be detected in any part of the world.

Test:	**A-24**
Date	08.05.88
Coordinator:	VNIIEF
Place	Zone B
Purpose:	Nuclear weapons development or perfection
Method	In a tunnel, $\overline{H} > 120$ m/kt$^{1/3}$
Products detected:	Onsite, RNG
Products released:	ICE (seepage of RNG)

The seepage of RNG in the EEZ occurred approximately 10 minutes after the explosion. The total amount of RNG entering the atmosphere was equal to approximately $4{\cdot}10^{14}$ Bq. The amounts of secondary strontium-89 and caesium-137 were equal to $1.66{\cdot}10^{13}$ Bq and $5.55{\cdot}10^{11}$ Bq, respectively.

The maximum EDR value at the technological site was equal to no more than 1 R/h. The RNGs were predominantly spread in a southerly direction and were not detected past the Chernaya Bay.

Summary

The radiation situation was regular and consistent with the forecast.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-27**
Date	04.12.88
Coordinator:	VNIITF
Place	Zone B
Purpose:	Nuclear weapons development or perfection
Method	In a tunnel, $\overline{H} > 120$ m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

The test is characterized as a fully contained explosion virtually without any seepage of RNG into the atmosphere. In this regard, constraints were not imposed by the weather conditions. Nevertheless, due to the complicated conditions of laboratory aircraft flights in December in this air mass propagation sector, additional radiation monitoring was provided using nuclear-powered icebreakers *Arktika* and *Rossiya*. Positioned in the Karskiye Vorota straits, the icebreakers recorded, 19 hours after the explosion, a fourfold elevation in background radiation due to the increase in the radon exhalation.

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

Test:	**A-13N**
Date	24.10.90
Coordinator:	VNIIEF
Place	Zone B
Purpose:	Confirm the reliability and improve the safety of nuclear weapons
Method	In a tunnel, $\overline{H}$ >> 120 m/kt$^{1/3}$
Products detected:	None
Products released:	None, CCE (gas containment)

Summary

The test is characterized as a fully contained explosion. At a distance of 100 m from the tunnel portal at the actual technological site, the EDR did not exceed 60 μR/h.. The representatives of the public who arrived at the test zone for the explosion time from the Arkhangelsk region and the Komi Autonomus SSR would clearly confirm this fact (see the official Act below).

Reference

No protest was lodged pursuant to the 1963 Moscow Treaty.

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4. EXPERT REPORTS

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4.1. NORTH TEST SITE: CHRONOLOGY AND PHENOMENOLOGY OF NUCLEAR TESTS AT THE NOVAYA ZEMLYA TEST SITE

Foreword

According to today′s formalized concepts on nuclear power utilization, nuclear test sites are treated as nuclear power installations for military purposes and their activities must include the concepts of protecting the population and the environment (air, water, flora, fauna) from ionizing radiation as well as the safe disposal of radioactive products (waste) of nuclear-explosion origin. [1]. As for the problem of the nuclear tests themselves, here everything is determined by political scientific and engineering aspects [2, 3]. Yet reality is different. As of 1 January 1997, five countries – the USA, France, Great Britain, China and the USSR have carried out 2049 nuclear explosions, including:

— USA – 1032 (of which 212 were in the atmosphere, five underwater and 815 underground; moreover, in addition to test site operation since 1950 in Nevada, the USA has also conducted nuclear tests in the Pacific ocean, on the Bikini and Enewetak atolls, on the island of Amchitka, and in the southern Atlantic, above the Christmas and Johnston Islands; One also cannot forget the fact that two nuclear bombs were exploded in 1945, over the Japanese cities of Hiroshima and Nagasaki);

— France – 210 (50 in the atmosphere and 160 underground):

— Great Britain – 22 in the atmosphere (and 23 underground jointly with the USA at the Nevada test site);

— China – 47 (22 in the atmosphere and 25 underground);and

— Soviet Union – 715 (216 in the atmosphere and space, three underwater, 496 underground, including 340 at the Semipalatinsk test site and 39 at the North Test Site, 117 were carried out in the framework of a programme of peaceful nuclear explosions in various regions of the country). Moreover, the last nuclear explosions were conducted in the USSR at these test sites on 19 October 1989 and 24 October 1990, respectively, and on 06 September 1988 for benefit of the national economy.

At present, no plans exist for conducting underground nuclear tests for engineering purposes, although the 1976 Treaty between the USSR and the USA ratified in 1990and the 1990 Protocol to the treaty on underground nuclear explosions for peaceful purposes foresees such an eventuality and it could be implemented as nuclear explosion technology for solving practical problems, particularly destroying large quantities of dangerous material and nuclear warheads.

The Soviet Union has stated numerous times its readiness to sign international agreements on the total banning of nuclear tests or on limiting the yield of underground nuclear explosions. The closure of the Semipalatinsk test site in August 1991 and the introduction of a moratorium on conducting nuclear tests for one year at the North Test Site starting on 6 October are the first unilateral steps taken by the Soviet Union towards substantially curtailing the test programmes. We should note that even earlier, the Soviet Union declared on numerous occasions a unilateral moratorium on nuclear tests.: during the period from 31 March to 30 September 1958 on atmospheric explosions (the USA conducted more than 30 nuclear explosions during that period), and from 6 August1985 for underground nuclear explosions; the term of this moratorium was extended four times and lasted until 26 February 1987 (the USA conducted 26 underground nuclear explosions during that period).

At the same time, the questions of assessing the radiological danger of nuclear tests and of monitoring their consequences remain urgent and call for a comprehensive discussion. For this reason , they were considered in 1991 in coordination with international government and scientific organizations, at the meeting of a group of Soviet and Finnish experts (Moscow, 28 February 1991in) and at a scientific symposium on the problems of preventing radiological consequences of underground nuclear tests (Ottawa, 23–24 April), conducted under the auspices of the Canadian Centre on Arms Monitoring and Disamament. Data on the conditions of underground nuclear tests at the North Test Site with steps ensuring their radiation safety and on the actual situation at the test site and the adjacent regions were exchanged [4, 5]. We should emphasize that in a special communiqué of the Canadian Centre of 25 April 1991, the data presented by the Soviet experts on conditions for ensuring radioactive product retention underground and criteria of radiation safety of underground nuclear explosions allowing for the heightened ecological requirements were recognized as extraordinary [6].

Introduction

Information characterizing the North Test Site at the Novaya Zemlya archipelago, its history and the phenomenology of tests practices, the original radiation background due to the combination of nuclear explosions in the atmosphere in the northern and southern latitudes, and the radiological parameters of the test site at present time (EDR, levels of caesium-137 and strontium-90 contamination levels) is presented in this report..

4.1.1. Novaya Zemlya Archipelago: brief historical reference

The first collective farm on Novaya Zemlya was founded in 1920, and in 1922, 22 reindeer were brought there. In 1924, 157 people were living on the archipelago, of whom 128 were Nenets; a Council of Novaya Zemlya Islands was set up, and Ilya Konstantinovich Vylko (Tyko Vylko) was elected its first chairman. He also became the first chairman of the hunting cartel set up in 1923, whose principal settlement was in Belushya Bay.

The issue of settling on Novaya Zemlya and building two radio stations there was considered for the first time by the Presidium of the State Committee for Planning Board on 16 November 1922. Its decision of 6 February 1923 was to construct radio stations on the coast of the Matochkin Shar straits and on Zhelaniya cape, and to set up a scientific base in the area of the Mitushikha Bay to study the west coast, and small hunting and natural resources of the archipelago. In summer 1923, the *Persey* vessel of the Separate Northern Hydrographical Detachment approached the coast of Belushya bay. On 14 August, three more vessels with barges arrived from Arkhangelsk at the northern coast of the Matochkin Shar straits in the area of the Bezymyannaya Bay. During one and a half months of intensive and selfless efforts, a village was built here, and on 6 October 1923, the "Matochkin Shar " radio station went on the air.

By 1930, the Northern Hydrographic Expedition had compiled sufficiently accurate navigation charts of the Novaya Zemlya coast, and a map of the Matochkin Shar straits, and had developed Kara Sea sailing directions.

Expedition activity on the archipelago developed further during the preparation and staging of the Second International Polar Year. In 1933, the All-Union Arctic Institute and the Leningrad Regional Geological Prospecting department directed expeditions to the archipelago under the leadership of V.K.Osipov and A.I.Zubkov. The expeditions had the objective of studying the Krestovaya and Sulmenova bays, carrying out general geological research and exploratory work on the southern coast of the Matochkin Shar straits about which only fuzzy and contradictory data were available.

By the mid-thirties, more precise concepts of the geological structure of Novaya Zemlya, and its mineral deposits, hunting resources, and economic resources had been developed. In 1936, M.M.Ermolaev, one of its enthusiastic explorers, summed up the outcome of the Soviet expeditions in his *Geologiya Novoy Zemli* (Geology of Novaya Zemlya) monograph and drew the general conclusion that there were no commercial reserves of mineral deposits on the archipelago Because of these findings, subsequent geological exploration of Novay Zemlya was curtailed and subsequently terminated.

In 1942, an anchorage of the Northern Fleet ships was set up by an order of the People's Commissar of the Navy (VMF) in Belushya bay whose objective was to build a base for defending Novaya Zemlya and its straits.

In 1947, two expeditions again visited the northern part of Yuzhnyi Island — one geological and one geophysical under the leadership of K.K.Demokidov and G.V.Gorbatskiy, which gave impetus to a detailed study of the mountain massif on the coast of the Matochkin Shar straits.

4.1.2. Development and Performance of the North Test Site

By 1954, 104 families were living on Novaya Zemlya. Due to the development of the test site on the islands and the need to ensure population safety, the Soviet Government asked the residents to consider the possibility of relocating to the mainland. An island wide gathering of all residents of Novaya Zemlya expressed a voluntary agreement to leave Novaya Zemlya, and the chairman of the council Tyko Vylko announced the decision "… of all people to return to the land of fathers and forefathers – the mainland, the endless Pechora Tundra" [7]. By Government resolution , the hunters received a subsidy and all their debts were paid. Housing was constructed on the mainland for the resettlers.

Pursuant to the Government resolution, the North Test Site was formed in 1954. It occupies an area of 90 200 sq. km, of which approximately 55 000 sq. Km are dry land. The test site made it possible to carry out nuclear tests in different media sincethe distance from its test areas to large inhabited localities is hundreds of kilometres (Amderma village – 300, Naryan-Mar town – 440, Vorkuta town – 560, Arkhangelsk city – 1000). Due to the absence of commercial reserves of mineral deposits, alienation of territory for the test site did not have a significant impact on the country′s economy and the economic and commercial activity in the region.

Tests at the test site were conducted on three technological test site areas geographically fixed to Chernaya Bay (zone A), Matochkin Shar straits (zone B), and Sukhoy Nos Peninsula of Sulmenova bay (zone C), (see Section 1, Fig. 1). Altogether (as of 1 January 1992), 130 nuclear tests have been carried, including 88 in the atmosphere, three underwater and 39 underground [8]. The most powerful test in the atmosphere — approximately 50 Mt — was also conducted at this test site. (During the period 1952–1960, the USA conducted four 15-Mt nuclear tests). The last test in the atmosphere was conducted on 25 December 1962, and underground on 24 October 1990. Detailed data on underground nuclear explosions carried out since 1964 are summarized graphically in Fig. 9. (Section 4.1).

4.1.3. North Test Site: phenomenology of nuclear tests

On the basis of the total energy released during the nuclear explosions detonated in the USSR, the contribution of nuclear devices exploded at the North Test Site reaches approximately 93%, whereas for the Semipalatinsk test site it is 6.1%, and for peaceful nuclear explosions - 0.9%, i.e. the North Test Site bore the brunt of nuclear tests. Here, the special (bombing) regime for conducting nuclear airbursts are implemented whereby nuclear devices are detonated at an elevation of H > 35 $W^{1/3}$ (m), which is substantially higher that the radius of the resulting fireball of, It is known [9] that during the first stages of a nuclear explosion, a highly overheated area of air — a fireball — from the central explosion area which is extremely bright reaches its maximum dimensions in fractions of a second (approximately 150m for an explosion with a 20kt yield). Since the explosion altitude is higher than the fireball radius, rarefied hot air saturated with evaporated explosion products floats to the upper atmospheric strata in the several minutes(higher than 10km) and is scattered there. Explosions at higher altitudes eliminated the appearance of local contamination zones; yet, in this case global radioactive fallout increases.

The following estimates are used for assessing the distribution of the atmospheric explosions carried out by all nuclear States by their contribution to global radioactivity: 12% for surface explosions, 75% for air explosions, and 3% for high-altitude (H > 10 km) –; 10% fall within global contamination sources due to the military nuclear-fuel cycle. [10].

Virtually all radioactive products which formed as a result of these tests were injected into the atmosphere during two periods: 1952–1958 and 1961–1962. Approximately 42% of the total energy yield of all nuclear explosions in the atmosphere due to the fission reaction was realized during the first period, and 47% during the second. The contribution of the tests carried out at the North Test Site to this distribution is approximately 27% and is fully determined by aerial nuclear explosions. On the whole, the distribution of the explosions carried out at the North Test Site by the total energy yield is estimated as 250 Mt for air - and underwater nuclear explosions about 239.6 Mt (allowing for the super-powerful explosion with a yield of approximately 50 Mt); and approximately 25.7 Mt for underground nuclear explosions

Underground nuclear explosions were detonated at the North Test Site in tunnels and boreholes. In recent years, the scaled depth of the charge placements has beenconsiderably increased, and special engineering designs are used to seal the stemming complexes which ensure aerosol product containment within the shaft volume. This helps to delay seepage of radioactive noble gases into the atmosphere, which, in turn, precludes violation of the provisions of the 1963 *Moscow Treaty* by the *radioactive fallout* criterion [5]. Furthemore, underground nuclear explosions as a rule, were conducted under conditions where the air masses were stagnant for extended periods time within the test site boundaries. Moreover, during the first 1–3 hrs after the explosion, the dilution of the contaminants contained in them reaches a factor of 10^{10}–10^{12} As a result, radioactive fallout beyond the test site boundaries virtually did not occur after any of the 42 underground nuclear explosions at the North Test Site.

4.1.4. The initial radiation background

Tests of nuclear weapons in the atmosphere which were conducted in the USA and in the USSR prior to 1963,, Great Britain (prior to 1959), France (prior to 1975), and China (prior to 1981) are the source for a gradual increase in background radiation around the globe. As a result of these tests, approximately $9.6 \cdot 10^{17}$ Bq (26 mln. Ci) of caesium-137 and approximately $7.46 \cdot 10^{17}$ Bq (20 mil Ci) of strontium-90 — the principal dose-forming radionuclides— and approximately $2.2 \cdot 10^{17}$ Bq (5.9 mil Ci) of carbon-14 were injected into the atmosphere.

The radioactive fallout peaked during the period 1949– 1966. Data on the accumulation of caesium and strontium radionuclides in the soil on average for the country between 1954–1975 are summarized in Fig.10; one can clearly see a tendency towards settling at a constant soil contamination level and even a decrease after 1966.. The dynamics of the radionuclide fallout on an average for the country are shown in Fig.11. Their concentration has been decreasing exponentially since 1965 as a result of which by the late 1970s, the soil contamination level in the country decreased to 3.4 kBq/m^2 (0,09 Ci/km^2) for ^{137}Cs and to 2,2 kBq/m^2 (0,06 Ci/km^2 for ^{90}Sr) At the same time, deviations from this pattern were observed in subsequent years due primarily to the nuclear explosions in the atmosphere periodically conducted in China (in particular, a 1.6 Mt in 1973 for fission, 2.4 Mt in 1976, and 0.45 Mt in 1980) These facts are illustrated in Fig. 12 which shows a relative increase in the amount of atmospheric fallout due to Chinese nuclear explosions, over the values obtained by extrapolation according to the exponential law.

4.1.5. Radiation situation in the nineties

Studies of the radiation situation cover all areas of Novaya Zemlya, both directly adjacent to test sites and inhabited villages removed from the test zones. The following entities were examined atmospheric fallout, soil, water (drinking, snow, sea), flora, and fauna. Generalized representative data on the ^{137}Cs contamination of various entities in Novaya Zemlya as a behavioural trend prior to 1990 are shown in Figures 13 and 14 (for comparison, data on a number of foreign sources for 1970–1975 are also presented). A constant decrease in the contamination level both in Novaya Zemlya and in other northern regions some 2–3 years after the cessation of the test series in the northern hemisphere can be observed [12].

As we have already stated, 39 underground nuclear tests have been conducted at the North Test Site since 1964. Moreover, a small amount of radioactive noble gases seeped during all of them to a varying degree but were retained within the test site territory for 2–5 days.. As a result of this process, $(0.9–1.85)\cdot 10^{14}$ Bq of ^{137}Cs formed due to radioactive decay of gases , which did not make a noticeable contribution to the radioactive contamination of the archipelago territory against the existing background [11].

The current levels of soil contamination with ^{137}Cs in various zones of the Novaya Zemlya islands vary within 1.2–3.7 kBq/m^2 (0.03–0.1 Ci/km^2). The maximum values indicate the presence of two local zones where atmospheric tests were conducted, with contamination levels reaching 40 kBq/m^2 (or 1 Ci/km^2) – zone C, and up to 2 kBq/m^2 (approximately 50 Ci/km^2) – zone A (Fig. 1., Section 1). These zones, whose radius does not exceed several hundred metres, are strictly contained and certified as sanitary-protective zones, with the gamma dose rate not exceeding a few units of μR/h.. On average, however, the exposure dose rate on the Novaya Zemlya islands is 8–12 μR/h and corresponds to the mean level in the adjacent regions (the Vaygach island, the Yamal peninsula, and the Yugorskiy peninsula). In the areas where bedrock outcroppings are seen on the surface, the EDR level reaches 16–25 μR/h.

In our opinion, there are no grounds to raise the issue about carrying out a wide scale decontamination programme on the territory at the test site, as was claimed by the Greenpeace organization, whose landing party penetrated the controlled (sanitary-protective) zone B [13]. There is no reason to think that "…such a vast region as Novaya Zemlya has been turned into a nuclear dump" as is being asserted very emotionally in one of the recent reports on the results of the survey of the part of the test site area, where prior to 1960, tests were carried out in the atmosphere [14].

4.1.6. Summary

In the foreseeable future, it is possible to carry out individual underground nuclear explosions at the North Test Site. In so doing,, all the requirements for adhering to specified radiation safety criteria and observing international agreements relating to environmental protection when using nuclear power should be observed [5, 15].

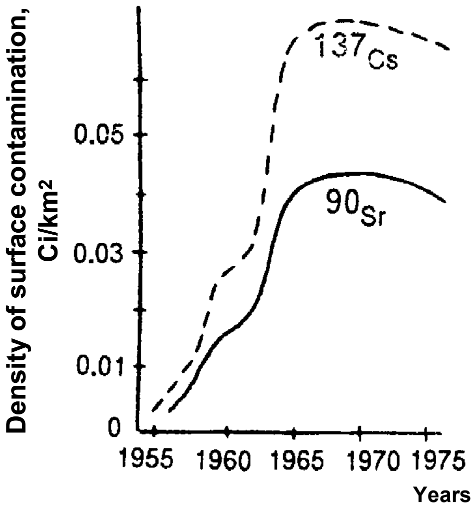

FIG. 10. Accumulation of cesium-137 and strontium-90 in soil.

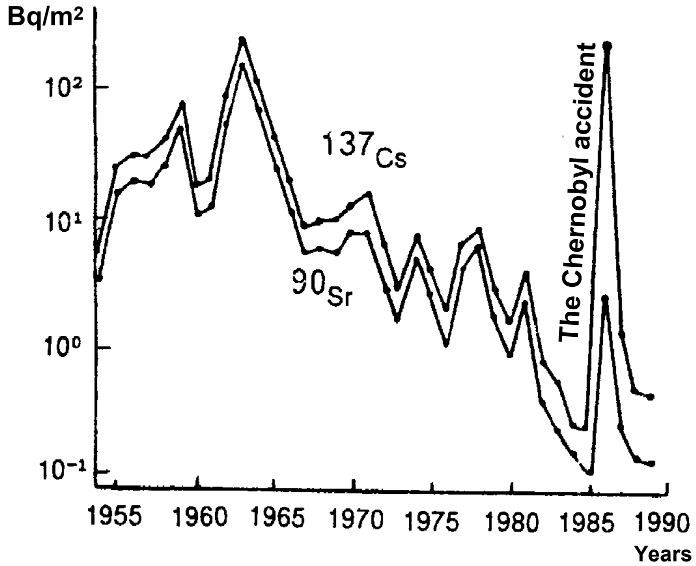

FIG. 11. Dynamics of the annual mean cesium-137 and stromtium-90 concentrations in the near-surface air.

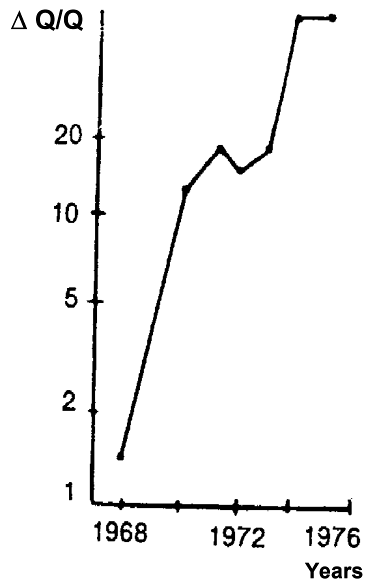

FIG. 12. Relative increment of strontium-90 fallouts (after tests in China).

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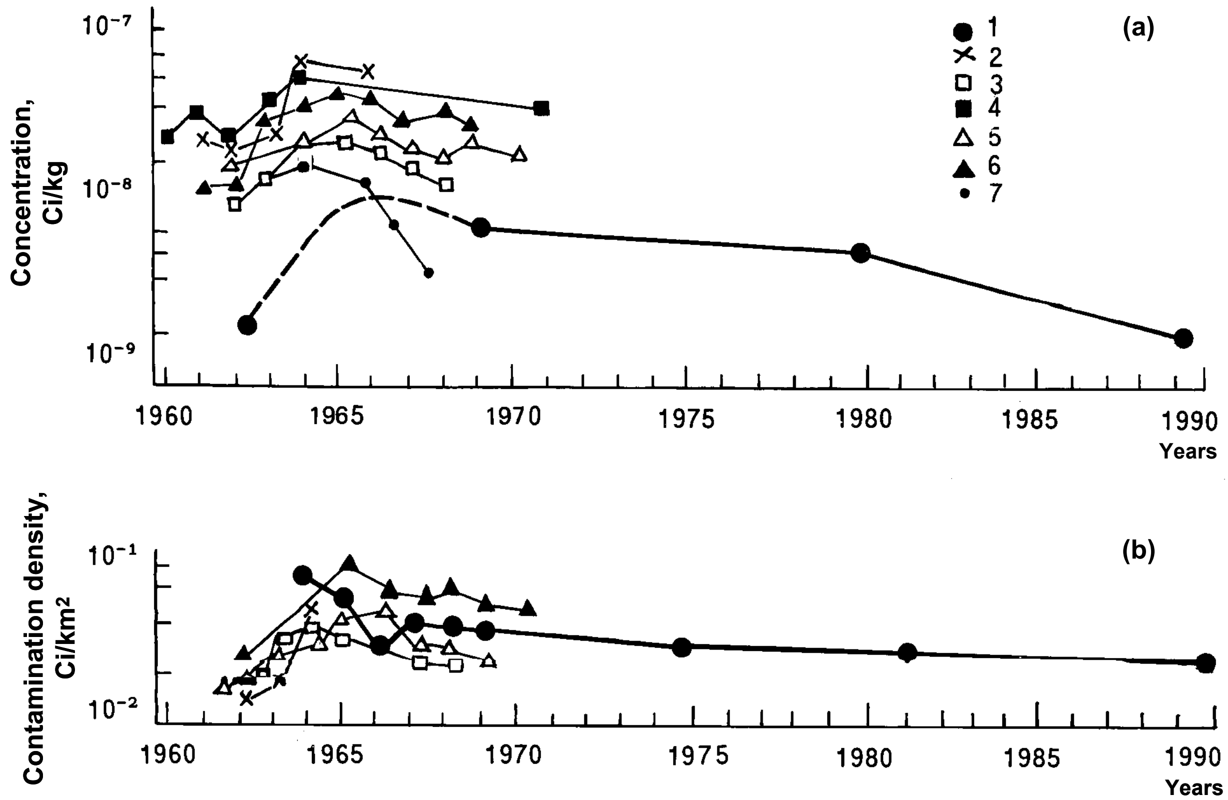

FIG. *13. Cesium-137 concentrations.*

(a) in dry lichen: 1 – Novaya Zemlya; 2 – Finland; 3 – Alaska; 4 – Anaktovuk-Pase; 5, 6, - two points in Sweden (two regions); 7 – Tule (Greenland);

(b) in soil: 1 – Novaya Zemlya; 2 – Finland; 3 – Ogotovuk; 5 – point 1 (Sweden), 6 – point 2 (Sweden).

Authors: V.G. Safronov, V.V. Chugunov

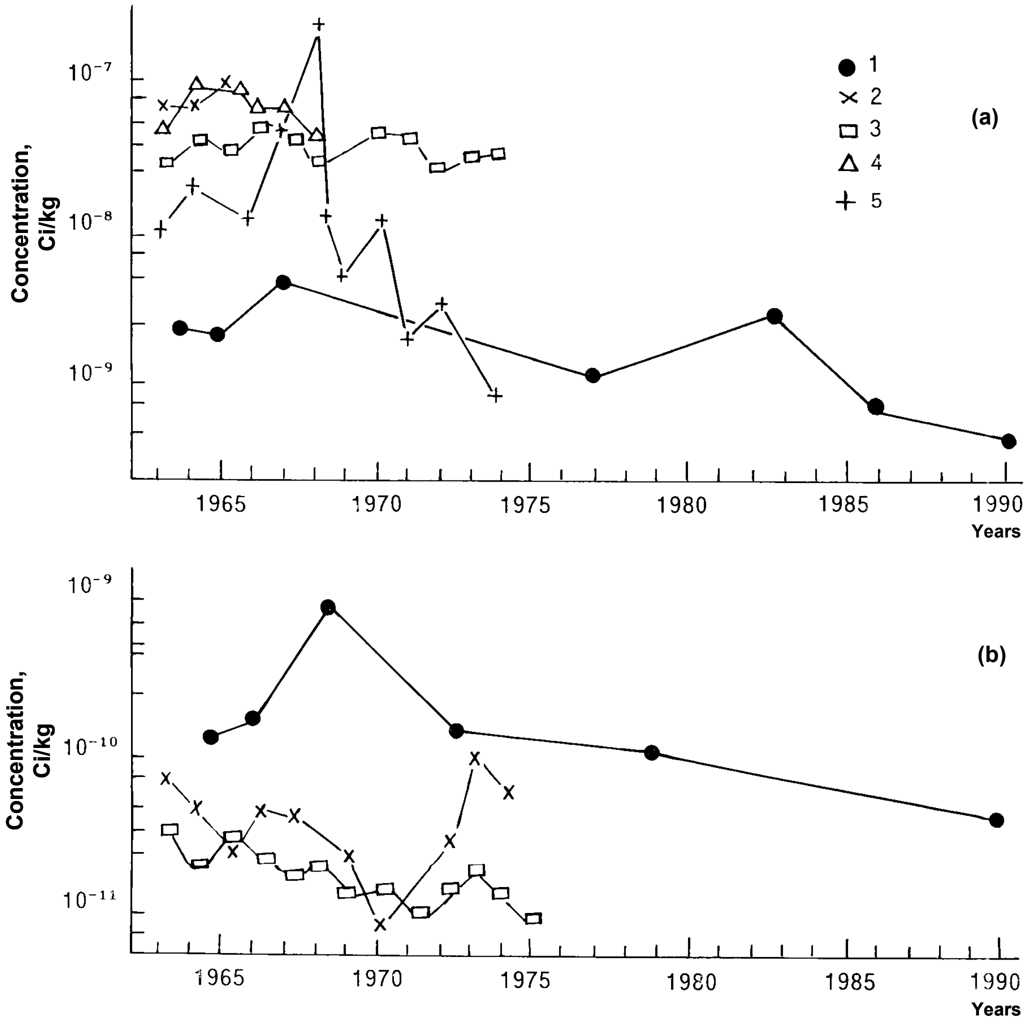

FIG. 14. Cesium-137 concentrations.

(a) in reindeer muscles: 1 –Novaya Zemlya; 2 – average for Finland; 3 – Alaska; 4 – average for Sweden; 5 – Greenland;

(b) in fish muscles: 1 – Novaya Zemlya, Gusinoye lake (loach); 2 – Greenland (cod); 3 – Farer Islands (different fish).

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In view of the fact that the most recent detailed survey of the North Test Site was carried out in 1976–1978, and in subsequent years only periodic observations were conducted at control points, it is expedient to set up radioecological monitoring, including that based on radiobiological studies of soil and logical entities with regard to the characteristic trophic chains, with an eventual goal of developing a biosphere reserve on Novaya Zemlya. Experts from Nordic countries could be invited to participate in examining a number of monitoring points on the test site territory, thus enabling independent expert examination based on joint representative samples. In particular, Finland has raised this issue.

The generalized data summarized in [16], show how — due to its biological peculiarities — the lichen-reindeer-man chain is the specific path by which ^{137}Cs and ^{90}Sr deposited on the earth's surface spread. The internal irradiation background among people included in this chain is higher than that of the population at temperate latitudes by twofold.. Yet no facts unambiguously attesting to the effect of testing on Novaya Zemlya on the ecological situation in the Arctic have been detected. No convincing relationship has been identified between the incidence of cancer or life expectancy of reindeer herdsmen and the existing levels of dose loads. In a large measure, these health parameters correlate with the severity of the climate and lifestyle habits of the indigenous population, factors which have been ignored thus far. One can criticize this conclusion, but it cannot be countered by other scientific work that would convincingly demonstrate the allegedly dominant effect of the radiation factor.

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4.2. RADIOACTIVE PRODUCT CONTAINMENT DURING UNDERGROUND NUCLEAR EXPLOSIONS IN GEOLOGICAL FORMATIONS OF NOVAYA ZEMLYA

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Introduction

Typical conditions under which underground nuclear explosions were conducted at the North Test Site in horizontal (tunnels) and vertical (boreholes) shafts for nuclear devices and the principal concept of underground nuclear explosion radiation safety are presented in this report allowing for the more stringent environmental requirements Data on the the geological formation of the Novaya Zemlya archipelago that determines the specific methods of conducting each underground nuclear explosion according to its scaled depth and the tamping complex of the charge placement working are presented A summary of all 39 underground tests carried out at the test site between 1964 and 1990 is presented in section 2. The following terms are used in the report filed pursuant to the 1990 protocol to the treaty between the USSR and the United States on limiting underground tests of nuclear weapons::

Explosion – denotes the release of nuclear energy from the charge container (canister);

Shaft – denotes any borehole or tunnel in which one or more charge containers are installed;;

Emplacement point – denotes the point at the shaft which coincides with the central point of the emplaced charge canister;; *Core sample* – denotes a whole sample of geological material, cylindrical in shape, whose dimensions are not less than 2 cm in diameter and 2 cm in length.

4.2.1. Principal premises of the concept of ensuring radiation safety of underground nuclear tests

Guarantees of radiation safety of underground nuclear explosions carried out under the conditions of the Novaya Zemlya test site are based on implementing the following criteria [1]:

— The scaled explosion depth ($\overline{H}$ = H/W$^{1/3}$) must exceed 120m/kt$^{1/3}$. The absolute depth of the nuclear device detonation must be greater than 150m for enclosing rock with gas content exceeding 15% mass, and more than 180m for rock with gas content of 15–30% mass. Large steeply dipping tectonic faults must be absent around the point of the charge container emplacement point to a distance exceeding the radius of the mechanical fracturing zone of enclosing rock;

— The start of the filtration or ventilation seepage of radioactive gas into the atmosphere must be greater than several tens of minutes later;

— The total amount of RNG entering into the atmosphere must be less than $3.7 \cdot 10^{16}$ Bq (10^6 Ci), and the activity of ^{89}Sr and ^{137}Cs formed in the atmosphere by the decay of radioactive inert gas chains should be less than $3.7 \cdot 10^{11}$ Bq (10 Ci) and $3.7 \cdot 10^{10}$ Bq (1 Ci), respectively.

The maximum possible containment of gaseous explosion products underground (with regard to both duration and amount) or adherence of absolute internal containment of the explosion is provided and determined primarily by the geology of the rock massif in which the test is being conducted. This actually determines the estimation of the parameter $\overline{H}$ and requirements for stemming complexes of tunnels and boreholes.

4.2.2. Features of the geological formation of the Novaya Zemlya archipelago

In a generalized form, the geological formation of the archipelago can be described as follows: [2, 3, 4]:

— The system of Novaya Zemlya is connected to the mainland Paihoy ridge (the Ural mountains), forming an independent folding system which is formed by Palaeozoic rock from the Cambrian to the Permian period;

— The total thickness of the Palaeozoic deposits reaches 10–12km, and they are represented primarily by terrigenic rocks — sandstone, clay shale — and, to a lesser extent, by carbonate rock (limestone, dolomite);

— The average physical and mechanical properties of the rock are: their density 2500–2700kg/m^3 due to sandstone, and shale; the seismic wave propagation velocity reaches 2200–5300m/sec; moisture content reaches up to 1%;and the gas content reaches up to 15%;

— The thickness of perennial permafrost rocks reaches 480–600m;

— The rock pitch angle reaches 40–60^o;

— According to the seismic conditions, the geological formation of the archipelago is classified as a virtually aseismic region; Tectonic disruptions on the bottom of the Barents and Kara seas are classified as the rift formations of oceanic mountain systems; no underwater tectonic faults have been found on the areas adjacent to the Novaya Zemlya islands; Such geology of Novaya Zemlya makes it possible to select sites for underground nuclear explosions that exclude the appearance of various types of deformations which may lead to unpredictable radiation consequences.

4.2.3. Conditions for localizing radioactive products of underground nuclear explosions with regard to the geology of the massif

A) On estimating thef mechanical effect of underground nuclear explosions on the rock massif

The principal parameters characterizing and determining the mechanical effect of an underground nuclear explosion and its primary radiation effects are:

(1) the explosion yield W, kt;

(2) the explosion depth H, m, and the scaled depth $\overline{H}$, m/kt$^{1/3}$.

At the charge depth over 120 m/kt$^{1/3}$, a containment zone is formed, which provides retention of the explosion products in the cavity before the moment of its collapse. At such depths, the split zone does not reach the fracturing zone.

(3) the radius of the nuclear explosion cavity $R = \overline{R_0} W^{1/3}$, m.

where $\overline{R_0}$ is the cavity scaled radius, which is determined by the strength properties of the rock, m; $\overline{R_0}$ = 9.3-11.2 m/kt$^{1/3}$.

As applied to the Novaya Zemlya test site conditions, the following dependence is recognized universally [5]:

$$R \approx \frac{56W^{0.31}}{H^{0.22}\mu^{0.09}} ,$$

where H is the depth of the nuclear device emplacement, m;

W is the nuclear device yield, kt;

μ is the rock density, t/m^3.

the gas pressure in the cavity P_0, atm.

$$P_0 \approx \left[\frac{10}{R_0}\right]^3 \left[\eta_{CO_2} + 4.7\eta_{H_2O}\right],$$

where η_{CO_2} and η_{H_2O} are gas content and moisture content of the rock, respectively,% mass.

Assessing mechanical effects of underground nuclear explosions on the rock massif, one uses the parameters of destruction zones near the charge emplacement point (Fig. 15.), generally on the basis of a calculation model for release of gaseous products from the rock massif into the atmosphere, in particular the one-dimensional model for filtration of the two-component mixture of gases (CO_2 and H_2O) allowing for vapour condensation and heat exchange with the rock.

In this description, only the conceptual approach to ensuring radiation safety of underground nuclear explosions is reflected but it characterizes the ways of taking into account the geology of the rock massif in which the explosion is detonated.

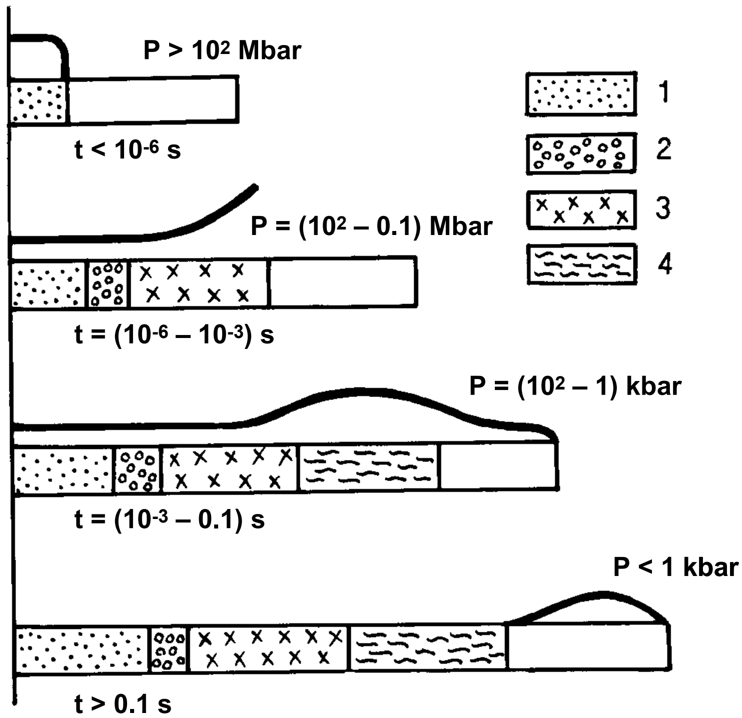

FIG. 15. Destruction zone near the underground nuclear explosion centre [9].

1 – evaporated rock; 2 – melted rock; 3 – fracturing zone; 4 – fissuring zone (discrete macrofractures zone). During propagation from the detonation centre, the shock wave evaporates, melts and shatters the rock, and discrete cracks appear at considerable distances. The magnitude and profile of the pressure pulse change with this (black curve).

B) Principal parameters of the mathematical model for numerical analysis of the radioactive release through the rock massif

The expert mathematical model for the release of radioactive products from an underground nuclear explosion zone is based on the following assumptions about the character of the physical processes that determine the effluent of RNGs together with cavity gases to the atmosphere:

- The movement of gases in the fractured rock is one-dimensional filtering flow of a primarily two-component mixture of gases appearing due to excessive pressure of gaseous products in the explosion cavity;
- The time of collapsing of the cavity is short compared with the time of gas movement in the rock;
- Pressure and temperature of gases in the cavity change due to leakage of the gases through the cavity walls;
- Heat exchange between the gaseous and solid phases occurs in accordance with Newtonian law;
- Water vapors are instantly precipitated on the rock;
- There is no movement of the condensed water in the medium;
- During the formation of the radionuclide composition of the moving radioactive products, two time intervals play the dominant role: (i) the time of RNG of separation from the halogens during the release of the RNG propellant gases from the cavity; and (ii) the time of the gas escape onset (T_o)into the atmosphere (T_0);
- during the movement of radioactive products together with gases in fractured rock, the aerosols forming due to the RNG decay are absorbed by the rock but in this case absorption of the RNGs themselves is not taken into account.

The equation set describing the movement of the two-component gas mixture under these assumptions is rather complicated and is not cited here. Yet by using this equation set in the frame of the adopted model, it appears possible to calculate the potential quantity of the RNG entering the atmosphere (e.g. in Bq/·kt). This, in turn, enables calculations of the limiting distances of their detection by modern radiation monitoring facilities (airborne, shipborne, and ground-based). In this sense, we should note that the amount of ^{90}Sr and ^{137}Cs in the atmosphere depends, other things being equal, on T_0, since their predecessors are short-lived radionuclides ^{89}Kr ($T_{1/2}$ = 3.2 min) and ^{137}Xe($T_{1/2}$ = 3.9 min). The total quantity of ^{89}Sr formed in the atmosphere is equal to:

$$Q_{89} = A_{89} \cdot W_{fis} \cdot \varphi_{89} \cdot \exp(-\lambda_{89} \cdot T_0) ,$$

where A_{89} is the total quantity of ^{89}Sr formed due to the ^{89}Kr decay during the explosion of 1 kt yield with fission: ($0.92 \cdot 10^{14}$ Bq/kt for ^{235}U and $3.1 \cdot 10^{14}$ Bq/kt for ^{239}Pu)

λ_{89} is the ^{89}Kr decay constant = 0.217 min^{-1};

W_{fis} is the energy yield of the fission part of the charge, kt;

φ_{89} is the part of krypton-89 injected into the atmosphere relative to its total amount at the moment T_0;

Then,

$$\varphi_{89} \approx \frac{\alpha}{\alpha + \lambda_{89}} \cdot \frac{P_0 - P_A}{P_0} \cdot \exp(-\alpha \cdot T_0) ,$$

where P_A is the atmospheric pressure, atm;

α is the cavity (source) depletion constant, min^{-1}.

$$\alpha = \frac{P_0 + P_A}{P_A} \cdot \frac{\psi \cdot \kappa_\Phi}{2(H-R)^2} \;;$$

$$\psi = 2\pi^2 \cdot \exp\left\{ -\frac{\pi^2}{2} \cdot \frac{P_0 + P_A}{P_0 - P_A} \right\} \;;$$

$$\kappa_\Phi = \frac{k \cdot P_A}{m \cdot \eta_B} \text{ m}^2\text{/min},$$

where m is the rock porosity,%; k is the rock permeability, in Darci;

η_B is the air kinematical viscosity, St.

$\kappa_\Phi = 630 \text{ m}^2\text{/min}$ at $H/R_0 \leq 6$;

$\kappa_\Phi = 2.92 \cdot 10^3 - 0.0185 \, H^2 \cdot R^{-2} \text{ m}^2\text{/min}$ at $H/R_0 > 6$;

$$T_0 = \frac{2\left(\frac{1}{6} + \frac{P_A}{P_0 - P_A}\right) \cdot (H-R)^2}{\kappa_\Phi \cdot \frac{P_0 + P_A}{P_A}}$$

C) Principal parameters of conditions for ensuring the confinement of radioactive products of underground nuclear explosions in horizontal mine shafts (tunnels)

The possibility of head pressure outflow of explosion gaseous products through the tunnel depends on the design of the stemming complex (SC). Given a typical SC, explosion products will not reach the tunnel portal if the following principal conditions are fulfilled (Fig. 16.):

$L_1 < R_{clp}$; $L_1 < R_{frt}$;

$L_1 < R_{clp}$; $L_1 \sim R_{frt}$;

$L_1 < R_{clp}$; $L_1 > R_{frt}$;

where R_{frt} is the radius of the fracturing zone, m;

R_{clp} is the radius of the collapse zone, m;

L_1 is the length of the line-of sight pipe, m.

The rate of the exposure dose at the first sealing wall (1) can be estimated for each of these conditions in order to be able to ascertain whether the radioactive products have reached the tunnel portal or not: in practice, if the exposure dose rate is greater than 10^4 R/h, they, as a rule, reach the tunnel portal and escape into the atmosphere relatively early. Complicated relationships exist that illustrate the possibility of varying different SC parameters in order to eliminate the escape of gaseous products into the atmosphere through the tunnel. However, in most experiments, various backup devices based on filtering materials which absorb and filter aerosols and iodine by gas blocking, artificial collapse (mechanical pipe closure) of the line-of-sight pipe (KVI in Russian), to prevent early floe of high velocity gas and debris, etc., are additionally used to increase the effectiveness of the SC operation in tunnels . These technical solutions have *know-how* status and are protected by patents.

D) Localization of radioactive products of underground nuclear explosions in vertical (borehole) shafts.

Given an underground nuclear explosion in a borehole with $\overline{H} >> 120$ m/kt$^{1/3}$, seepage of RNG is possible along the intercable space in the standard SC (Fig. 15.). The start of the efflux onset ($T_{o(bh)}$ has been established experimentally and is equal to the following (in hours):

$$T_{0(ic)} = 2.2 \cdot 10^{-4} \cdot \exp(0.115\,\overline{H}) .$$

In other words, the process is rather extended, which makes it possible to take the necessary preventive measures for containing the RNG or for substantially lowering their outflow through this channel.

4.2.4. Practical results of ensuring radiation safety of underground nuclear explosions at the North Test Site

A) Primary radiation effects of underground nuclear explosions

Due to proper selection of the conditions for conducting an underground nuclear explosion, such as the explosive device emplacement depth allowing for the geological characteristics of the enclosing rocks and the design parameters of the SC, and due taking account of the air mass propagation during the tests, it was possible to carry out all 39 test underground nuclear explosions without violating the provisions of the *Moscow Treaty* of 1963.Yet in the cases where RNGs did enter the atmosphere, their seepage was, as a rule, of low intensity. As a result, during the entire period when underground nuclear explosions were conducted, only $(0.9–1.8) \cdot 10^{14}$ Bq ^{137}Cs formed in the atmosphere with its precipitation primarily overthe test site territory [6].

Reference

More detailed information about the radioactive effect of the underground nuclear explosions carried out at the Novaya Zemlya test site are presented in Section 2 using a principle borrowed from the authors of the reference report on tests at the US test site in Nevada [7].

B) Long-term radiation consequences of underground nuclear explosions

The cavity of an underground nuclear explosion and the adjacent fracturing zone can be treated as a prototype of the areas (disposal) for long-term (permanent) burial of radioactive waste [8] [8]. On both the Novaya Zemlya and other test sites, *fields* of radioactive zones have been formed, each of which is *storage* for highly-radioactive waste of explosion origin, including several kilograms of ^{239}Pu, ^{235}U, ^{234}U, ^{238}U, ^{3}H, buried in natural massifs without any engineering barriers. And these are real facts. Yet what is also real is the fact that these products and other refractory and weakly volatile products of explosion origin are prinarily *vitrified* in the explosion cavity in the mass of molten rock, which mass is 400–800 t/kt TE, virtually in the form of glass.

The total activity of explosion products is relatively low. While in a standard generating unit of a nuclear reactor with electric power of 1 GW, approximately 1 t of uranium burns up during the year and approximately 1 t of fission products form as a result. In the case of a typical underground explosion, only 200–600 g of fission products are formed, i.e. thousands of times less. Radionuclides in the body of the molten rock are self-buried and are highly diluted; 80–90% of them are concentrated in the solidified melt *lands* at the bottom of the nuclear cavity [9]..

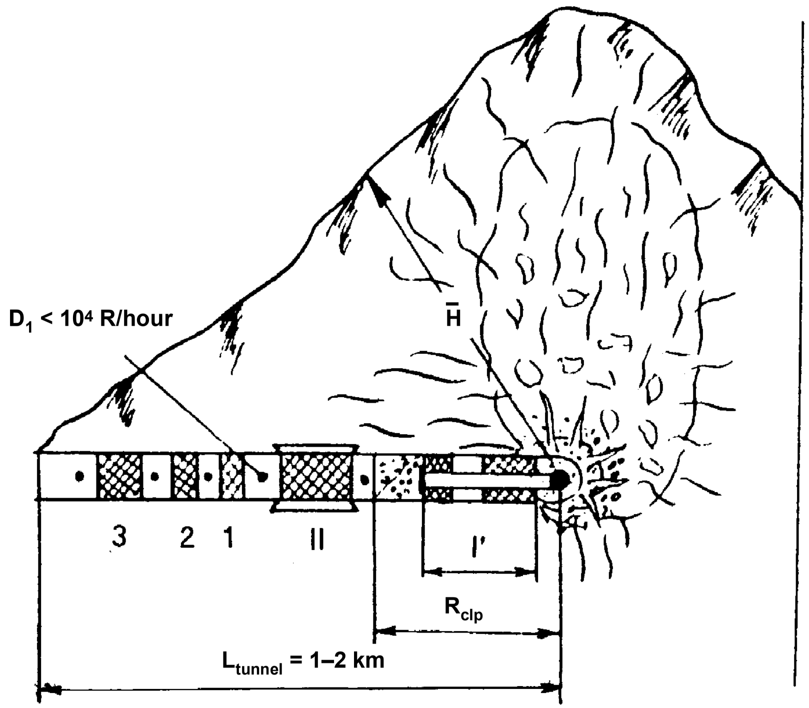

FIG. 16. Underground tests in a horizontal tunnel.

(36 underground nuclear explosions; $\overline{H}$ >(90÷120)$W^{1/3}$, m;
L_1 – line-of-sight pipe length; I, II – stemming complexes;
1, 2, 3 – sealing walls).

Safety criteria for underground nuclear explosion: 1) $\overline{H}$ >> 120m/$kt^{1/3}$; T_0 >> 10 min; 3) $Q_{S89,137} \leq 10$ Ci; 4) $\eta_{CO2+H2O} < 15\%$ weight; 5) taking into account the tectonics, and voids in rock; 6) technological decisions to seal the stemmingcomplex ($L_1 < R_{clp}$).

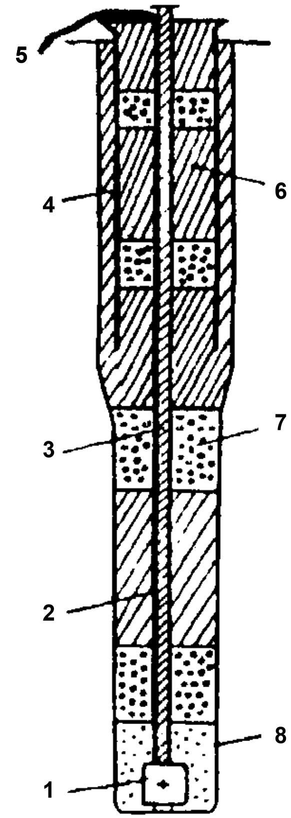

FIG. 17. Underground tests in a vertical shaft (borehole).
(6 underground nuclear explosions; $\overline{H}$ >> 120$W^{1/3}$, m).

1 – container; 2 – cable bundle; 3 – emplacement pipes; 4 – casing pipe; 5 – cable bundle; 6 – concrete stemming; 7 – detritus stemming; 8 - iron ore concentrate.

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Currently, there are no data attesting to the fact that under these specified conditions any radioactive nuclides are leaking. Obviously, the safety of such zones is primarily due to their inaccessibility by water. If there is no access of water to the radioactive melt, during its direct contact with the rock, the radionuclide diffusion factor is so low (10^{-19} cm^2/sec) that they will move only some meters in one million years. Yet contact with water flow may lead to a migration of radioactive products into the rock massif. However, even here real radioactivity product migration does not exceed 0.1–1 m/year. Consequently, test site explosion fields which already have proper infrastructure can be treated as promising for explosion-type self-burial of radioactive (and especially dangerous) substances or as points for passive deep burial of industrial waste. Furthermore, it is expedient to consider underground nuclear explosions as an alternative to destroying nuclear weapons [10, 11].

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4.3. THE NORTH TEST SITE: ASPECTS OF ENVIRONMENTAL MONITORING

Ya.E. Doskoch

The test site in the Novaya Zemlya archipelago is an installation with an island status, which makes it necessary to take into account the direct relationship between the consequences of the tests carried out in the maritime environment, the vulnerability of the northern landscape, and the conditions of the glacier existence.

In the stratigraphic and structural methods developed by the Swedish glaciologist H.V. Ahlmann and the Soviet scientist P.A. Shumskiy, improved in recent decades, and also as a result of the use of isotopic analysis by the Dane V. Donogor of glacier cores obtained by deep drilling, the role of ice as the storage medium of information about changes in the natural environment in the past was identified, and prospects for using these data for predicting the development of the natural environment on a regional and global scale where the glacial regions of the Arctic play a special role were outlined.

With regard to the foregoing, incorporation of new cartographic material (including space-based) also makes it possible to obtain principally new information about the glacier fluctuations in the Novaya Zemlya archipelago and to establish the principal glaciation development patterns by the correlation between glaciation and the sources of the precipitation feeding the glaciers. Along with estimates on glacier behaviour, these data obtained for Novaya Zemlya are the first necessary link in predicting the evolution of glaciation and clarifying the likely long-term consequences of underground nuclear explosions.

It is clear that, judging from data already accumulated, current types of explosions (in particular with a yield of less than 150 kt) do not lead to catastrophic tectonic phenomena Yet even if we assume that converse processes occurs during the explosions, i.e. localized relief of stress in the region due to a series of induced small earthquakes, especially if we take into account the fact that modern glaciation of the arctic, and that includes Novaya Zemlya, has been developing under the conditions of complex interaction between the maritime environment and the atmosphere and the underlying land [1, 2], then any tectonic shifts due to underground explosions may affect the character of the glacier existence in the long run.

Figure 18. shows that, without characteristics of these very important natural components of high latitude , from the viewpoint of their influence on the formation and life cycle of glaciers, one cannot understand the characteristic features of the processes not only in glaciation of the arctic as a whole but also the processes occurring in the natural environment which have consequences on a planetary scale.. Consequently, it would be interesting if the USSR Academy of Sciences summarized marine geological and geomorphological data [1, 2, 4] and their correlation with quaternary events on the coast (Fig. 19) which make it possible to state that an analysis of the behaviour of the edge of the glacial cover, a study of the correlation between meteorological data of snow accumulation and melting, and an analysis of the material balance in the glacial cover should be included into the programme of environmental monitoring in Novaya Zemlya due to recent underground nuclear explosions.

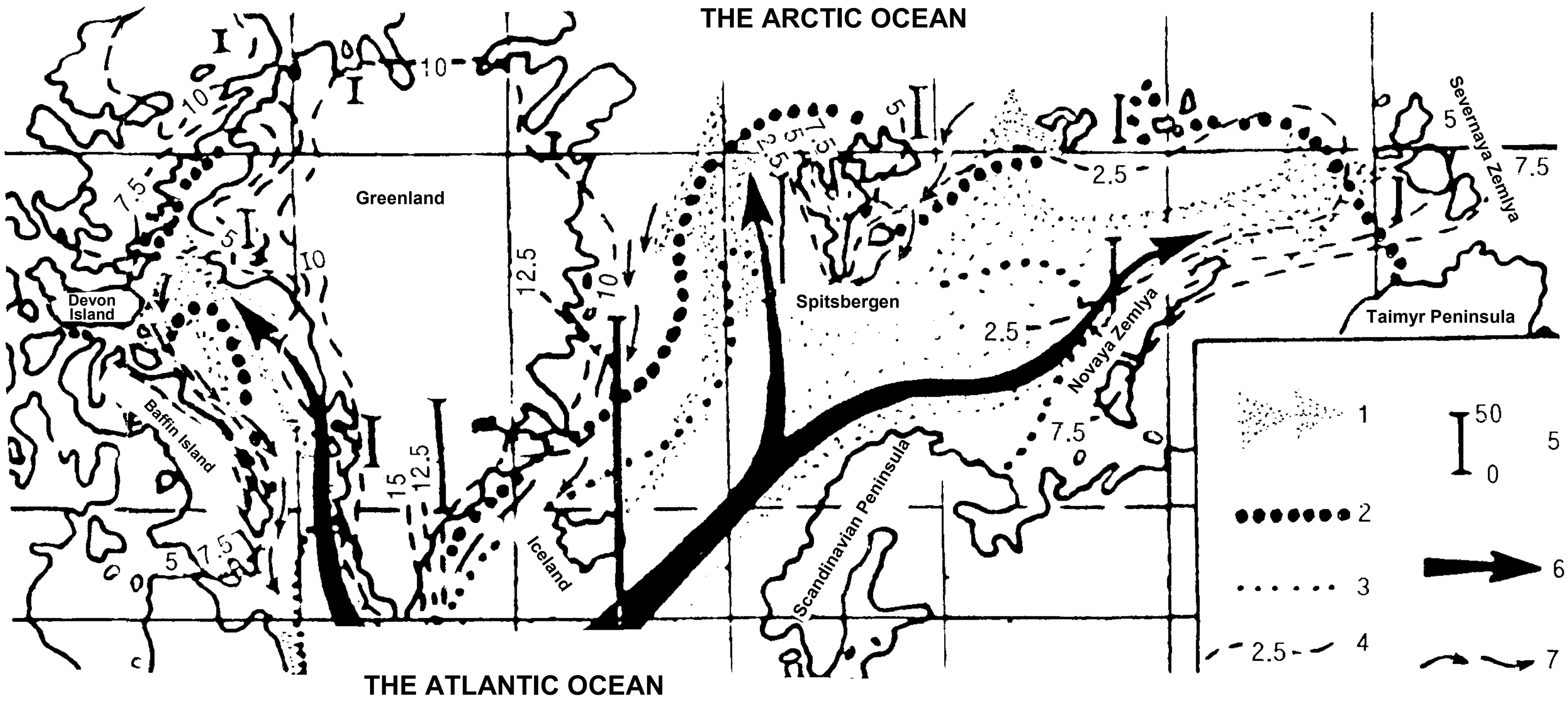

FIG. 18. Conditions for glaciers existence in the Arctic.

1 – principal paths of heat and moisture inflow;
2 – boundary of sea ices during thesummer;
3 – boundary of sea ices during the winter;
4 – altidude of the feeding boundary, hundreds of m;
5 – accumulation of ablation at the feeding boundary, g/cm^2;
6 – warm currents;
7 – cold currents.

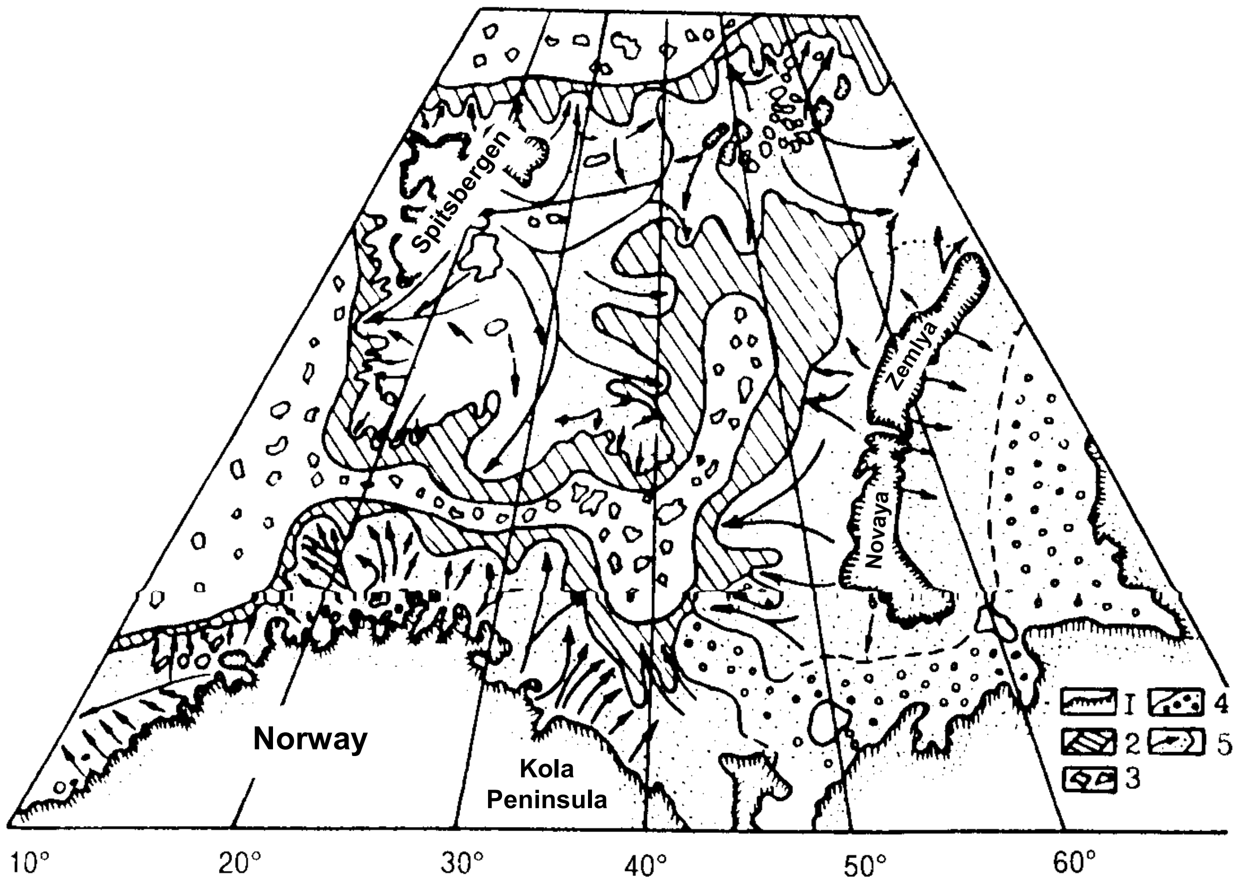

FIG. 19. Likely development of the continental glaciation on the shelf on the Barents Sea in the late Pleistocene (18–20 thousand years ago).

1 –areal of land ice (on-bottom);
2 – floating shelf mainland glacier;
3 – packedices and drifting icebergs;
4 – island permafrost of the sea bottom;
5 – land (bottom) ice and lines of its movement.

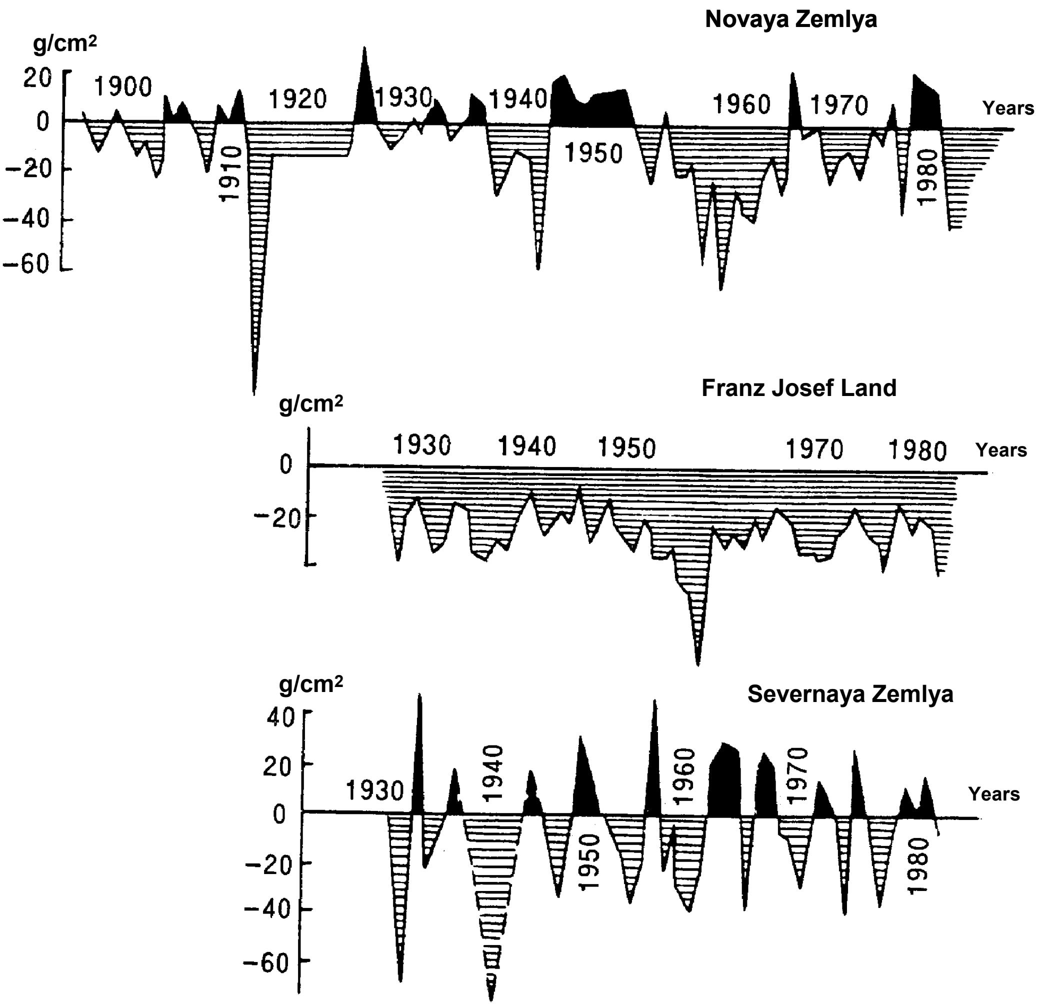

FIG. 20. Variation of the matter balance of glaciation in Novaya Zemlya, Franz Josef Land and Severnaya Zemlya.

This monitoring must be organized by zone since the predominance of the glacier types in Novaya Zemlya makes it possible to identify different glacial areas of complete, incomplete, and mountainous glaciation, and also small glaciers. In particular, locations of small glaciers to certain terrain forms and their inherent orientation attest to the effect of local conditions on formation of these type of glaciers. The orientation of mountain-slope glaciers on the coastal escarpments is due to the Novaya Zemlya bora with prevailing direction from the island centre towards the coast, while the orientation of the river-bed ice is determined by the direction of the local erosion network, which, in turn, is embedded in the systems of young non-tectonic dislocations. An increase in glaciation from the south towards the north of Novaya Zemlya is distributed according to the latitude zonality principal and is attributed primarily to the inflow of air masses which bring moisture from the Barents sea. The same orientation is also observed on the glacier feeding boundaries: they rise up to 300 m from east to west within the northern (Severniy) island. Precipitation to the glaciers of Novaya Zemlya is characterized by quite complicated regularities.

The material balance of the glacier cover of Novaya Zemlya as a whole was calculated for the period from the and of the last century until the present on the basis of observations conducted in the framework of the international geophysical year [1, 2, 5] (see Fig. 20) and may serve as an important component of monitoring in the Novaya Zemlya region.

The protection of northern seas has great environmental and social implications since it is necessary to take into account the effect of various forms of human activity on the habitat of marine plants and animals, including operations at the test site and at the facilities which pose radiation danger in Novaya Zemlya. From this viewpoint, the ecosystems of polar seas surrounding the Novaya Zemlya archipelago are of special interest. It is known that neither of the arctic seas has such a variety and diversity of flora and fauna as the Barents sea.. This body of water remains the most promising in the north for fisheries and other maritime economic activities.. This determines the expediency of monitoring the pollution of the hydrosphere and its inhabitants in the test site zone, although the hydrobionts themselves have relatively high radiobiological resistance.

Today, many of fundamental environmental problems of the northern seas, particular energy aspect, are poorly know: the mechanism of photosynthesis in algae remains unclear, there are no reliable data on the productivity of Northern Sea ecosystems, and it is difficult to establish the real biomass of the leading sea organisms as well as such important quantities for hydrobiology as the biological productivity of the communities.

In addition to the temperature, light, and salinity, exogenic factors are quite noticeable in the plankton and benthos habitat under arctic marine conditions. Geomorphological phenomena play a controlling role in the functioning of the maritime ecosystems, especially against the background of the geological history of the polar seas. The net effect of the activity of exogenic factors is manifest in the mixing of substances from high hypsometric levels (shelf, photic ocean zone) to lower levels, with direct participation of gravitational force, which is accompanied by change in the established ecological equilibrium. The predominance of abiotic components, enhanced in recent years due to an increase in the human-made load, is accompanied by changes in the relationship and exchange among the biotic components, including the phytoplankton, phytobenthos, bacteria, zooplankton, ichthyofauna, marine mammals, birds, and organic detritus.

In the light of the coastal ecosystems, pelagial and benthal organisms dwelling in the maritime environment play a determining role in forming the bioproducts;. e.g. approximately 77 million tons of organic carbon is formed due to phytoplankton but only 0.4 million tons due to phytobenthos in the coastal areas [3].

In addition to the heat content [4, 6], it is necessary to mention the salt content as an important factor affecting the functioning of polar ecosystems and the rates of substance flows, the stratification of the water depth (the pycnocline), internal waves, rings on various scales and of different origin, topographic phenomena, and the presence of ice and other factors on a global scale (Fig. 21.). It is clear from the environmental scheme for the Barents sea shown in Fig. 22 that, in order to predict and make timely and operative decisions after the appearance of undesirable trends or the development of extreme environmental situations, it is necessary to set up functional models of the ecosystem and construct biocentric relationships both horizontally and vertically and also to develop mathematical programmes and simulation models.

In generalizing the information accumulated in scientific literature about anthropogenic influence on the systems of the Barents and Kara seas, one can note that noticeable shifts in the ecological environment in the region began in the mid-60s due to an increase in commercial fishing, an increase in the conventional and emergence of a nuclear-powered fleet, escalating loads on the northern seaway, an expansion in oil and gas exploration, and an increasing human interference of in the fragile northern network of ecological systems (Fig. 23.).

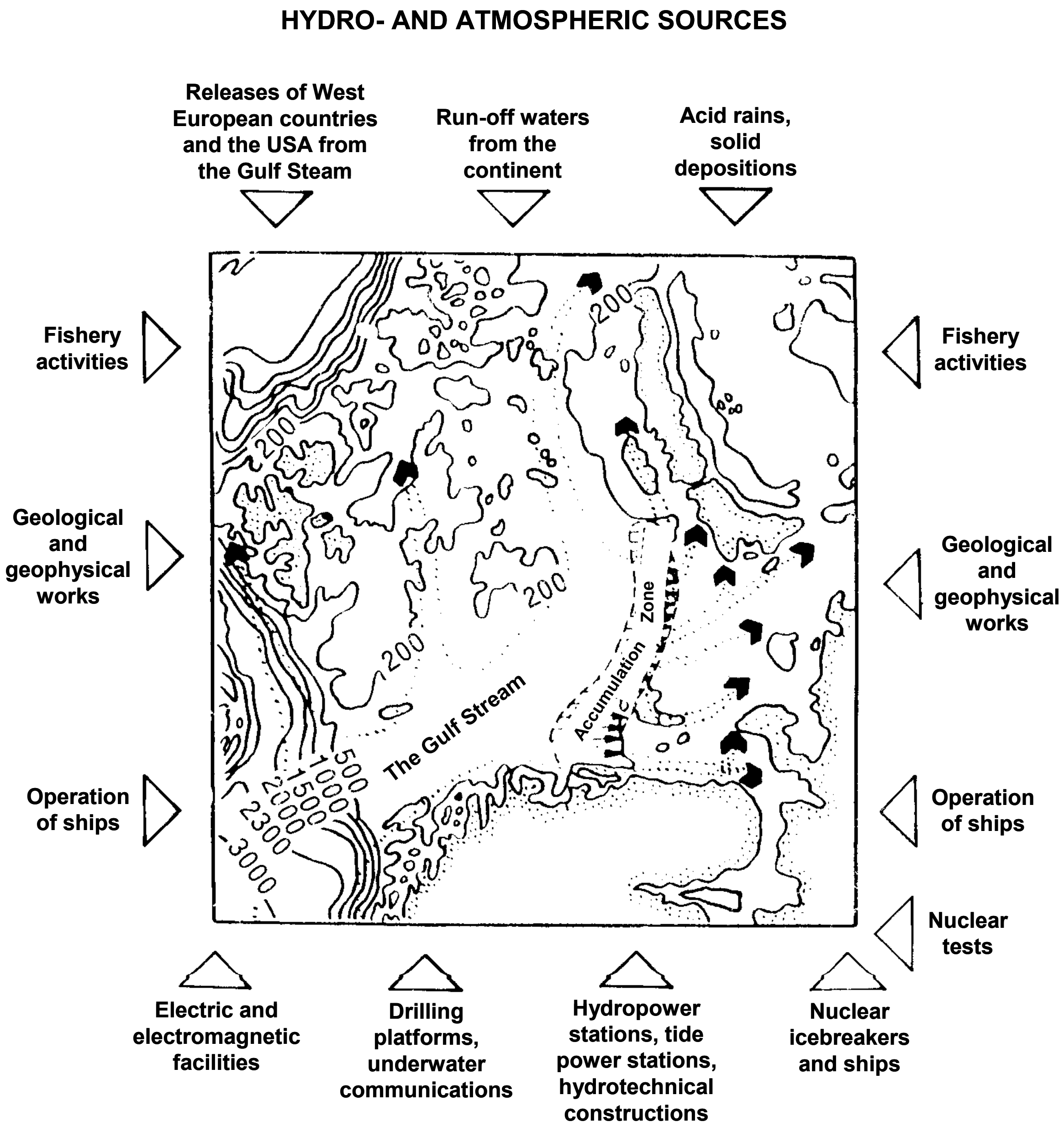

FIG. 21. Sources of anthropogenic influence on the Barents sea ecology.

According to the data of the Kola Branch of the USSR Academy of Sciences [6, 7], the vertical contaminant distribution assumes the form represented in Fig. 24 while the spatial distribution of hydrochemical parameters is shown in Fig. 25.

It is known that the character and direction of currents in this region are such that the eastern section of the Barents sea and the western coast of Novaya Zemlya are gradually turning into the largest European dump lying above the littoral. Vast amounts of nylon, plastic, polyethylene, glass, and metal waste whose decomposition takes hundreds of years have been accumulated.. The water, shelf, and bottom sediments have been contaminated with industrial by-products which may be grounds for assessing the scale of the damage inflicted by the European countries and considering compensation. The role of the radiation factor which arose due to the nuclear weapons tests is little known in this region. At the same time, we know that a large quantity of radioactive substances from West European countries are spreading along the Scandinavian peninsula, and entering the Barents and Kara seas (Fig. 26.). The highest concentrations of ^{137}Cs (up to 30 Bq/m^3) are observed in the southern part of these seas and directly near Novaya Zemlya [7]. The maximum concentration of ^{90}Sr measured in the Barents Sea exceeds the steady-state value due to the global fallout by approximately twofold. More accurate assessments of the contribution to the radioactive contamination level of the Barents and Kara seas in the Novaya Zemlya region can be made by analysis of diagnostic calculations of the dynamic structure of the water [8].

Radiation monitoring at the test site and around it is based on the assumption that measures to select the site depth of the charge emplacement, taking into account of the geological conditions, and the mine shaft sealing make it possible to eliminate the escape of radioactive explosion products to the surface. In this case, seepage of radioactive short lived noble gases is permitted if the dose rate of γ-radiation beyond the test site boundaries does not exceed the values of fourfold the natural background [9]. In our opinion, the assumption does not take into account the fact that in addition to radioactive noble gases, the gaseous effluent contains other ingredients. Where underground nuclear explosions are used to destroy highly toxic chemical waste, this fact becomes especially important since gas effluents (leakages) may contain the components which are being destroyed but did not break down as well as the breakdown and/or synthesis products of new compounds resulting from the unknown processes combined with the high temperatures and pressures and with the natural gaseous environment and rock.

Underground nuclear explosions for the aforementioned purposes should be accompanied by environmental monitoring measures, which include environmental certification of the test site, identifying the vulnerable chain links of local ecosystems and risk zones; instrumental measurements of the levels and radiation and chemical pollution of the atmospheric air, surface and underground water, soil cover, glaciers, snow cover, plants and hydrobionts (an analysis of trophic chains); identification of priority pollutants, a calculation of their scattering fields, and monitoring (bioindication, special and computer charts and a study of interrelations between pollutants); development of an environmental information system structure and its hardware for the test site (software, space-time dynamic models of the atmosphere, climate, aqua-cosystems, land-cosystems, and anthropogenic impacts, database and methodology for prognosis of the state of the environment on the basis of multiple analysis and development of the environmental situation under various scenarios); and the creation of a network of stationary environmental monitoring stations (practical realization of environmental monitoring, including early warning system).

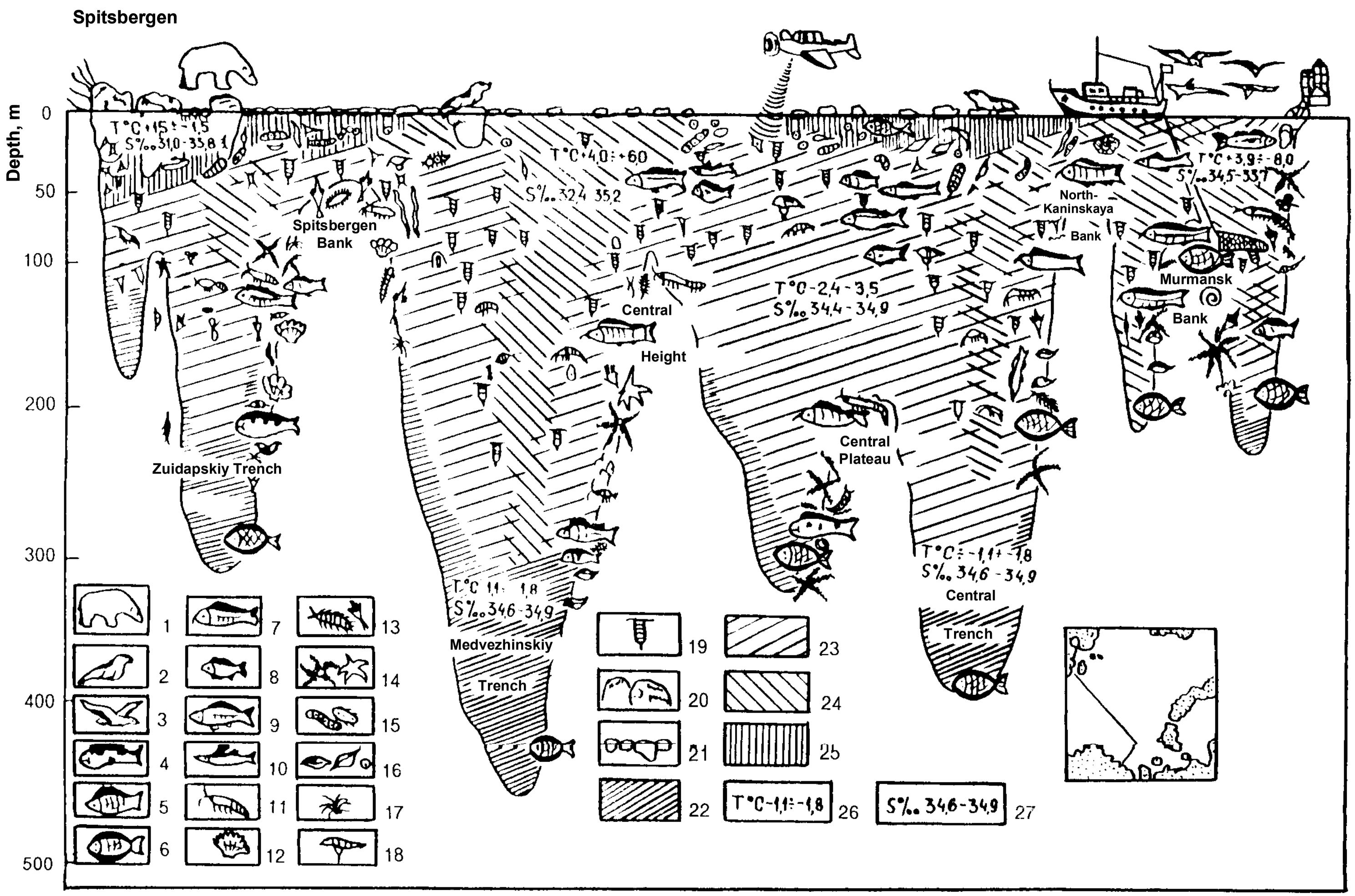

FIG. 22. Ecological chart of the Barents Sea.

Habitats of: 1 – bears, 2 – marine animals, 3 – birds, 4 – lancet fish, 5 – flounder, 6 – halibut, 7 – cod, 8 – ocean perch, 9 – salmon, 10 – Mallotus arcticus, 11 – shrimp, 12 – scallop, 13 – britsleworm, 14 – sea stars, 15-16 - Diatomaceae, 17 – sea-urchins, 18 – Pteropoda mollusks, 19 – Calanus and other Copepoda; 20 – icebergs, 21 – sea ices, 22 – -bottom Arctic waters, 23 – coastal waters, 24 – Atlantic waters, 25 – Arctic water masses, 26 – Barents Sea waters and water temperature, 27 – water salinity.

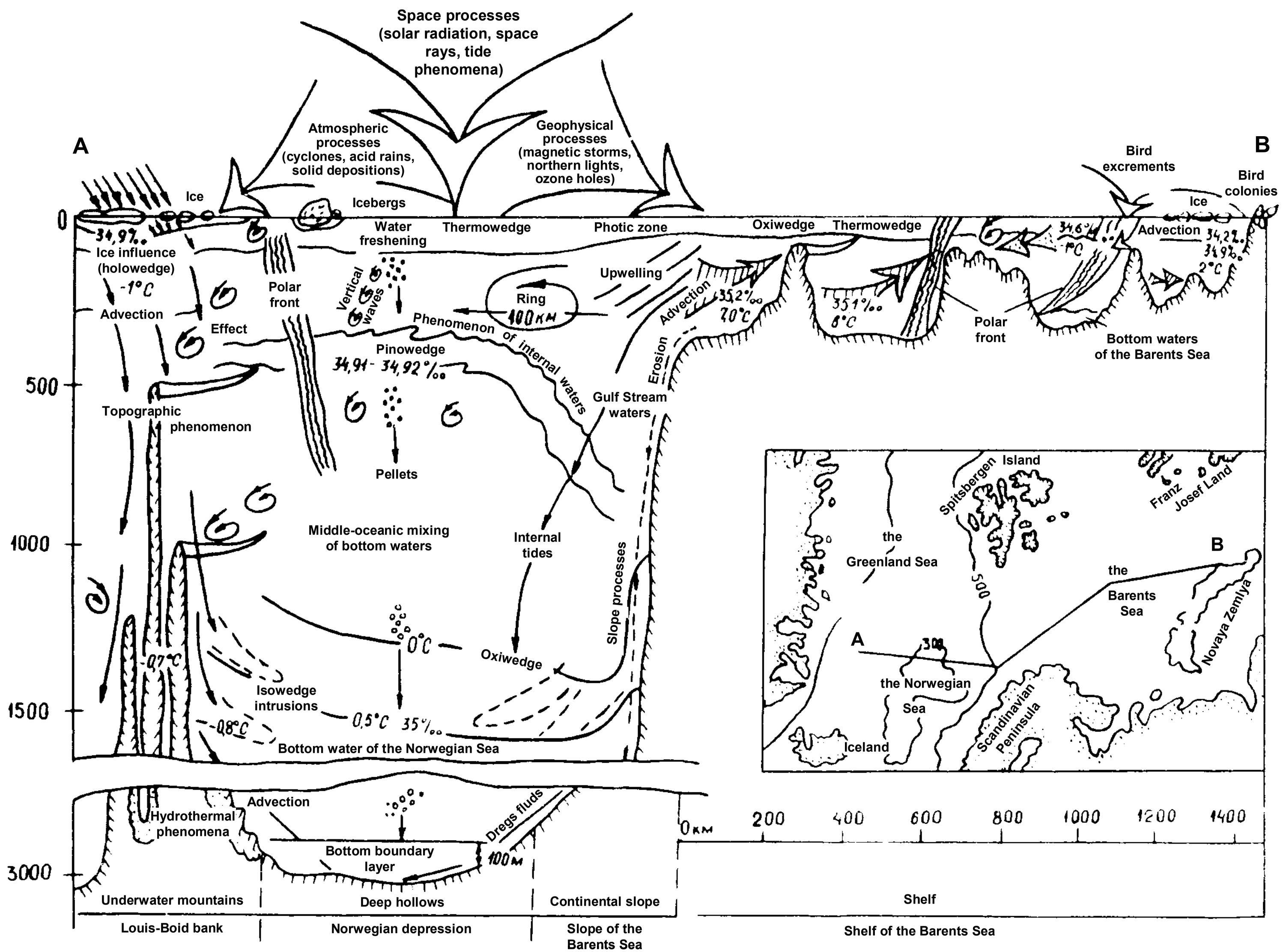

FIG. 23. The scheme of interrelation of the habitat factors of the northern Europe sea organisms.

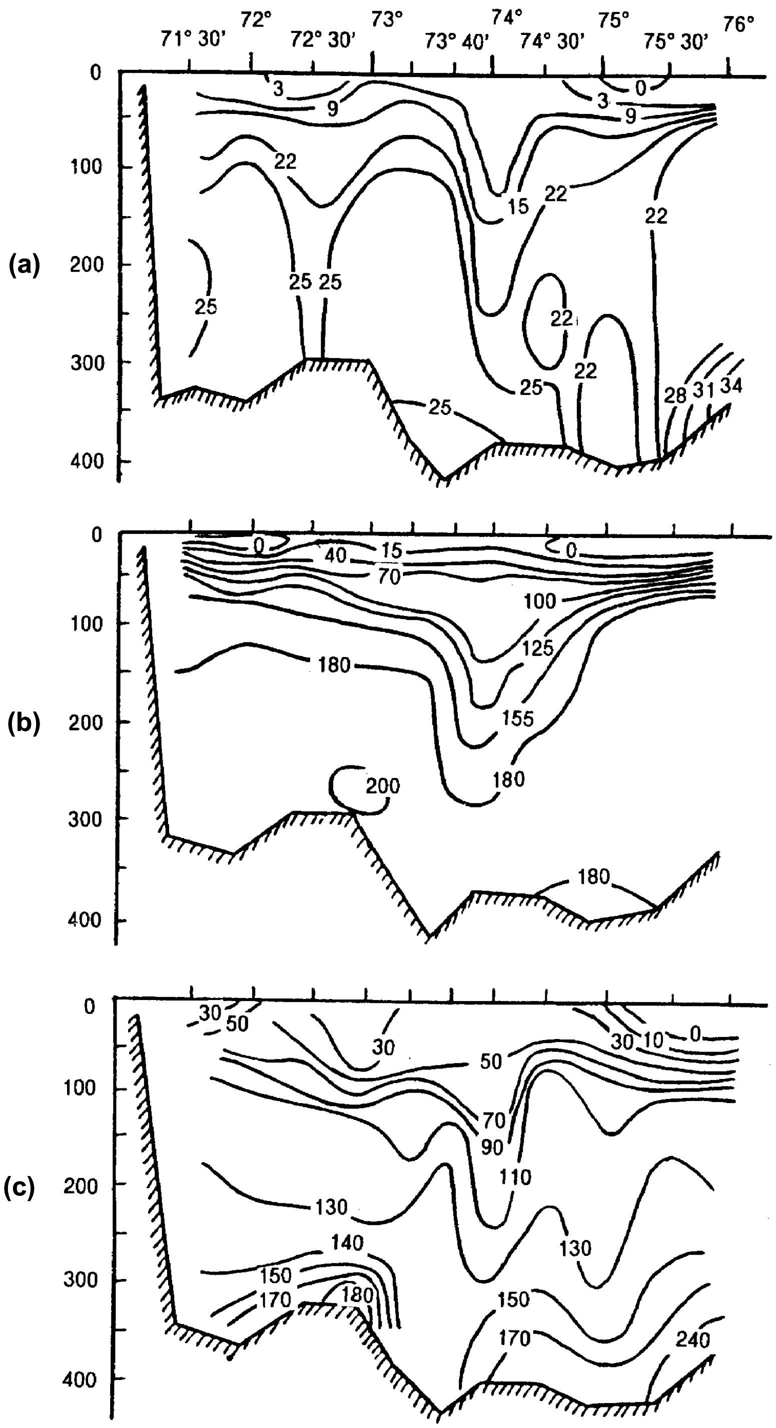

FIG. 24. Biogenic substances distribution (µg/l) in the western part of the Barents sea (in June 1987).

a – mineral phosphorus; b – nitrate nitrogen; c – silicates.

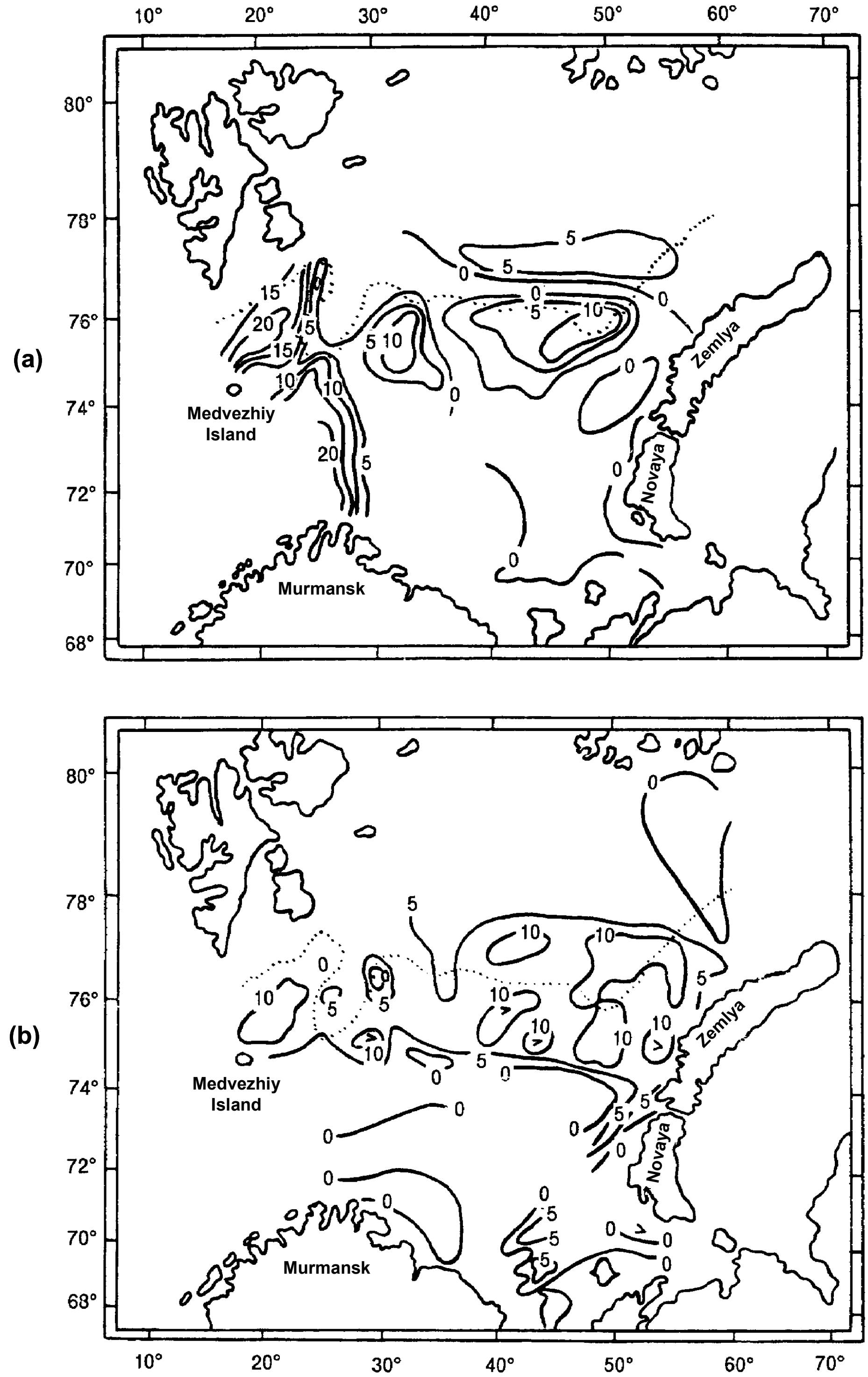

FIG. 25. Nitrates and phosphates distribution (μg/l) in surface water of the Barents sea (summer of 1984).

a – nitrate nitrogen; b – mineral phosphorus. The dotted line denotes the polar front position.

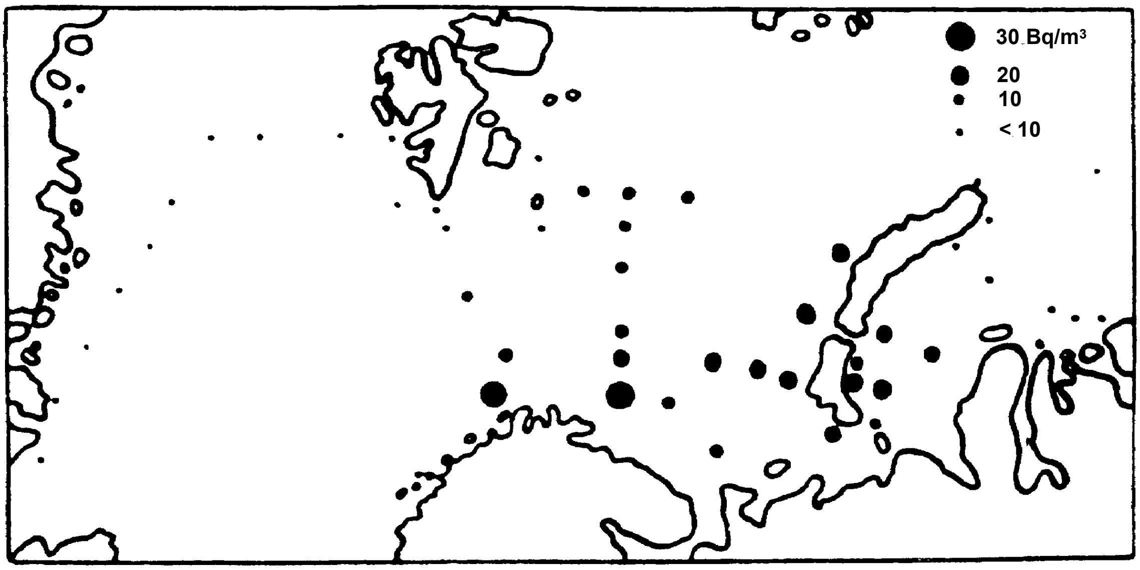

FIG. 26. Caesium-137 concentration in surface water of the Barents and Kara seas.

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4.4. NUCLEAR TESTS: RADIATION MONITORING AND SAFETY

Yu.V. Dubasov, A.S. Krivokhatskiy, A.M. Matushchenko, V.I. Filippovskiy

In the last two years, articles and works of fiction have appeared in various publications which accused all involved in carrying out the nuclear tests in the country of *criminal radiation* and other sins. In so doing, the following three accusations are made either directly or indirectly: 1) people and animals are exposed as a result of the nuclear tests: 2) these nuclear tests are poorly monitored or monitoring does not detect all harmful consequences; and 3) the government and defense agency are still classifying and deliberately concealing from the public the results of the radiation impact on the environment.

Yet, radiation monitoring of nuclear tests has been carried out since the first test in 1949. It is evident and natural that in a country impoverished by war, there were simply not enough resources under the conditions of the ongoing arms race to adequately ensure the safety of both direct test participants and the population and the safety of the entire habitat as a whole. The USSR put forward proposals to completely ban all tests prompted by the understanding of the need to solve the general safety problem in the most radical and economical way and suggested as an intermediate step to ban the tests in three media —I the atmosphere, space, and underwater, i.e. the tests which inflict the greatest harm to humankind and nature. In 1963, an agreement about such a ban was signed by the USSR, the USA and the UK but not all nuclear-weapon States have joined it: We should recall that since 1963, France has set off approximately 44 nuclear explosions in the atmosphere, the last one of which took place on 15 September 1974 while China conducted 22 tests, most recently on 16 October 1980.

Since 1964, the USSR has conducted all tests only underground. And for this type of test, a large number of institutes at the Ministries of Defense, Medium Machine Building Industry (Minsredmash), and Public Health, the State Committee on Hydrometeorology, and the Academy of Sciences have been charged since the very first domestic underground nuclear explosion with carrying out research into radiation factors of underground nuclear explosions in order to justify, development and implement measures aimed at comprehensively reducing the harmful impact of underground nuclear explosion radiation on the environment and, in the final analysis, on the population. Moreover, this involved studies both during military explosions detonated for the purpose of perfecting nuclear weapons, increasing weapons system safety, and studying the effects of its combat employment and during peaceful nuclear explosions whose wide-ranging programme has been under way since 1965.

We can confirm that the main cost of carrying out nuclear tests for both purposes is for ensuring their safety and for radiation monitoring, and is again aimed at improving the practices of subsequent tests in order to increase safety. Large teams of scientists, engineers, and technicians participated in these efforts and carried out radiation-dangerous operations directly at the epicentral zones and in underground tunnels. The scientific data they obtained in the past 30 years serves today as the basis for designing and operating all radiation protection devices which are being implemented in all testing and peaceful underground nuclear explosions. The experimental equipment used in this research and in radiation monitoring is sometimes of inferior quality to known similar foreign prototypes. Nevertheless, our knowledge about the processes of radiation environment formation is not inferior and the engineering designs for carrying out the explosions (despite the aforementioned general relative lack of resources) are, as a rule, not worse, and in many cases better, than foreign analogues.

This is confirmed by the programme of 124 underground nuclear explosions carried out in the country for the purpose of the national economy which ensured sufficiently low emergency levels (in particular, in none of the four *peaceful explosions* during which an unpredictable escape of certain quantities of radioactive substances to the earth`s surface occurs was there any danger of excessive staff exposure, and much less so for the population). On the basis of information available to us, reports appearing in the press about cases of damage to people's health from radiation from any underground nuclear explosion carried out in the territory of our country are groundless.

The escape of radioactive products to the earth`s surface — and these are usually only the radioactive noble gases — has been reliably monitored in its dynamics in each explosion using diverse facilities for various explosion types. These data are available for each underground nuclear explosion, and, for the principal types of explosions, a comparison has been made with theoretical forecast models making it possible to improve the calculation methods for assessing the radiation impact of the explosion and its radioecological effect. In a number of cases, the isotopic composition of the released gases has been examined in order to monitor the explosion parameters, and radiochronometry has been used to reconstruct the pattern of its development underground where physical sensors have been largely destroyed. Thus, a picture of its development underground has been restored when the physical detectors were mostly destroyed.

About 20 underground explosion zones in various media were stripped using research shafts and borehole systems. This made it possible to establish the melting and solidification patterns of the rock and its capture of radionuclides as well, and also the spatial distribution of the isotopes of the various chemical group elements and the stability of the solidified radioactive melts to the effect of underground water. The transport of radionuclides with underground water has been examined for the principal types of rock and explosion arrangement versions. The dose fields and soil vegetation radioactivity have been measured in all test site and epicentral zones and in adjacent territories. Although not all the instrumental methods used are up to date, the database for both test sites and areas of single peaceful explosions are unique and sufficient for drawing the conclusions of the radiation impact of those underground nuclear explosions, and for carrying out environmental impact examination.

Equipment and procedures used and their results have shortcomings clearly visible to the professionals. Efforts being made under the special comprehensive research programme *Region* for 1991–1995 are aimed at eliminating them (allowing for the contribution of *old* surface tests). Emphasis is placed on the insufficient regional knowledge about hydrogeological conditions at the test sites. This is primarily determined by the high cost of research into the regional hydrogeology which has not allowed a sufficiently full experimental rather than model conclusion on this issue due to scarcity of resources.

Moreover, the *old* underground nuclear explosions need to be revised according to the IAEA criteria for burying radioactive waste in geological formations. These criteria were developed in 1980 so could not be directly taken into account in designing explosions, although scientists and designers have long suspected that these criteria existed and used them in a non-formalized fashion. Nevertheless, today such a revision would be useful both for clarifying the effects of the events long past and for considering those in the future.

Finally, the analyses of the body burdens according to the radionuclide transport chain from explosion zones to humans (through drinking water, air, dust, vegetation, animals) based on radiochemical analysis of environmental entities must be compared to the harmful factors from other types of exposures inherent in specific regions, namely the influence of proximate thermal electric power plants and fossil fuel power plants,, chemical and metallurgical works, fertilizers and insecticides spread on the soil, etc. Such efforts were initiated in 1988 by a committee under the leadership of Professor A.F.Tsyb, and must be continued on the basis of more systematic and complete data. Their coordinated application must be made a cornerstone due to the fact that these data on effects of each test explosion are available to the Ministries of Defence and of Public Health and data for peaceful explosions,-to design organizations and institutions that carried out these tests. Open submission of data summaries, in turn, should demonstrate to the concerned public the true state of affairs today and develop an objective attitude by the public to the test site and the conduct of peaceful nuclear explosions for industrial purposes.

With regard to tests carried out at the Ministry of Defense test sites, the *Region* programme has been under way since 1991 with the cooperation of scientific research institutions (Fig. 7, Section 2) in the framework of a common scheme of systematic studies of the radiobiological and seismic effects of the test sites on the region (Fig. 8, Section 2). At the same time, with regard to the suggestion by an advisor to the President of the Russian Federation on environmental issues, A.V. Yablokov, about the expediency of developing a single state radiation nuclear explosion monitoring service, this programme can also be extended to 're-evaluating' (state environmental expert examination) peaceful nuclear explosions which were carried out in various regions of the country.

With regard to the absence or concealment of data (presumed to be sensitive) on the radiation effects of underground nuclear explosions on the population, such data are currently available and were available immediately after each explosion and were not concealed from the decision-making authorities. Yet transmission of this data to mass media was thought, as a rule, to be inexpedient since among the general public, there are virtually no people with the training and experience necessary for correctly and objectively assessing this information. It is possible that this is a wrong viewpoint. Nevertheless, using the Chernobyl example, we can today see numerous cases of misunderstanding, even among experts in seemingly kindred fields whereby this information was incorrectly attributed to the true state of affairs and the events and phenomena which, upon proper investigation, had no relationship to Chernobyl were attributed to the radiation factor.

Of course, radiation just like fire and automobiles is a dangerous weapon in the hands of non-professionals or socially irresponsible people. Yet underground nuclear explosions and other types of human activities, when properly monitored, may and should be safe, at least to the extent determining their economic, political, or social benefit. science and engineering provide methods and resources for monitoring them. The degree to which safety is ensured during the underground nuclear explosions is substantially higher than in almost all remaining types of human activity. Underground nuclear explosions, in addition to their military and potential national economic significance, also yielded numerous scientific results which could not have been obtained by other means. The scientific and technological potential which ensures the radiation safety of underground nuclear explosions is being used, e.g. in mitigating the consequences of the Chernobyl nuclear power plant catastrophe and if it were not available, these consequences could have been much more tragic, protracted, and costly.

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4.5. UNDERGROUND NUCLEAR EXPLOSIONS IN THE ARCTIC FOR PEACEFUL PURPOSES

K.V. Myasnikov, V.V. Kasatkin, K.V. Kharitonov

Forty-two underground nuclear explosions for military purposes were conducted prior to 1991 in the arctic at the country′s North Test Site (Novaya Zemlya archipelago). At the same time16 underground nuclear explosions were detonated near the arctic circle in 1971–1988 in the framework of a programme for using the nuclear explosion technology for the national economy (see Fig. 27.). Until recently, data on such, explosions (between 1965 and 1988, a total of 124 were set off in various regions of the country) had not been widely described in the mass media. This deprived the public of the possibility of judging either the expediency of conducting them in each case or their radiation consequences. However, starting with the 1960s, considerable attention has been paid to these issues in domestic and foreign scientific and engineering literature [1-7]. Moreover, now the 1976 Treaty between the USSR and the USA *On Underground Nuclear Explosions for Peaceful Purposes* and the 1990 Protocol to to the treaty have been ratified, which legitimizes the possibility of such uses of nuclear power.

In the region of the arctic circle, peaceful nuclear tests were conducted under contract to the former union ministries, primarily Geology, Mineral Fertilizers, and Non-ferrous Metallurgy, for the purpose of deep seismic sounding of the Earth's crust in order to search for the structures with promising mineral deposits, to crush ore at an apatite deposit, to extinguish a gas jet and to develop a tailing reservoir storage dam at the Udachninskiy ore mining and processing enterprise. All these projects were implemented by specially developed nuclear-explosion technology and were subjected to an expert examination by the USSR State Committee on Hydrometeorology and Environmental Monitoring, the *Gidrospetsgeologiya* Special Waterworks Geology Production Geological Association, the USSR Geology Ministry, the Public Health Inspection of the USSR Public Health Ministry, and the Geophysics Institute at the USSR Academy of Sciences pursuant to existing regulatory documents. In a number of cases, the examination was carried out by the USSR Ministry of Defence for rock with a structure similar to that at the Semipalatinsk and North Test Site. . The commissions specifically set up for this purpose monitored all types of production work in preparing for the explosions while their conduct was supervised by a State committee and expedition group of experts carrying out an interdepartmental comprehensive programme of radiation monitoring and radiation research at each installation.

Of the aforementioned 16 peaceful nuclear explosions, 14 were conducted as the explosions of complete contained and were not accompanied by radioactive contamination of the atmosphere and terrain. During two explosions (*Kristall*, 2 October 1974, and *Kraton-3*, 24 August 1978), some radionuclides escaped into the atmosphere leading to radioactive contamination of segments of the terrain in the air mass propagation direction In this case, an insignificant escape of gaseous products into the atmosphere from the Kristall explosion was planned and called for by the design conditions of the charge emplacement in order to create an earth-filled dam. The process of gaseous explosion product filtering through the mound of broken rock was always under control and did not exceed the limits of calculated forecasts. The radiation safety of these efforts was completely provided by technical measures, choice of favourable weather conditions and season, the work schedule and continuous radiation monitoring.

In contrast to the *Kristall* site, the unexpected escape of the radionuclides into the atmosphere occurred at the *Kraton-3* site due to the low quality of borehole stemming. The radioactive gas jet after this explosion travelled up to 150 km over the unpopulated forest-tundra terrain. Characteristics of the radiation situations at these sites are summarized below.

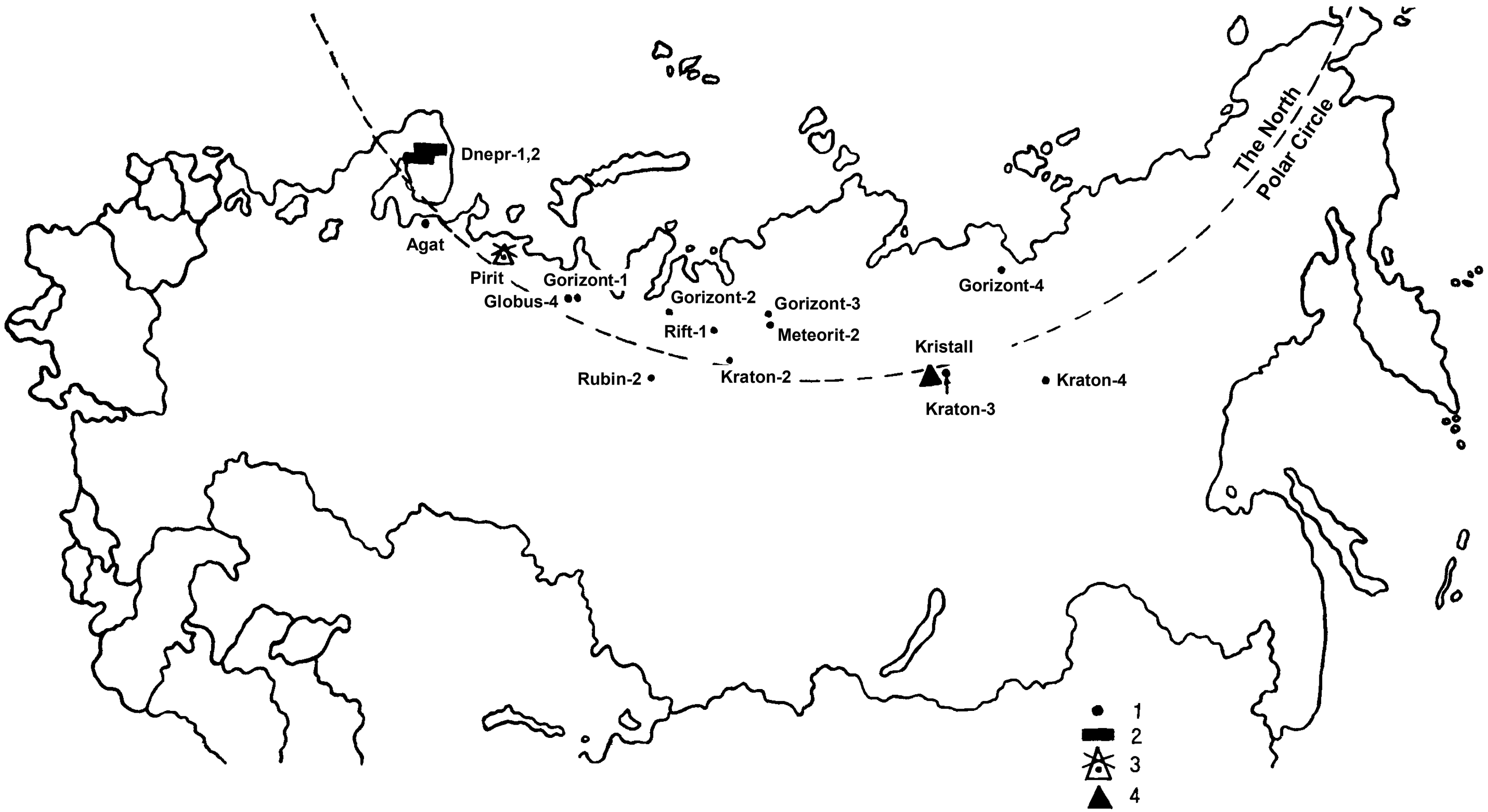

FIG. 27. Underground nuclear explosions for industrial purposes (in the region of the arctic circle).

1 – deep seismic sounding of the Earth crust for the purpose of searching for thestructures promising for mineral prospecting (customer: USSR Geology Ministry)
2 – exploratory industrial works on ore fracturing (customer: USSR Mineral Fertilizers Ministry)
3. – exploratory works on extinguishing (capping the well) a gas gusher (customer: USSR Geology Ministry) 4 – exploratory works on creation of a reservoir dam by bulking (bloating) therock (customer: USSR Nonferrous Metals Ministry)

Authors: V. Myasnikov, V. Kasatkin

"***Kristall* site**: in the epicentral zone — a hill (mound) in the form of a frustum of a cone with a radius of approximately 80 m and a height of up to 8 m, whose surface is covered with tundra vegetation. According to the data of an aero-gamma-spectrometric survey carried out by the central exploratory surveying expedition of the Geological Production Association of Yakut Geology in 1990, the γ-radiation levels in a 0.4 x·0.9 km^2 sector in the area of the underground explosion epicentre were mainly 15–30 μR/hour, the maximum value being 110 μR/hour; trace amounts of ^{60}Co and ^{137} Cs were detected and identified in the soil level of the mound (less than 50 Bq/kg). No radioactive nuclides were detected in the water samples taken from the mound (the sensitivity of the analysis methods was less than 0,1 Bq/l for ^{137}Cs and less than 100 Bq/l for tritium). Since this site is located in the permafrost region, radionuclide migration with groundwater is strongly hindered.

The *Kristall* site is of almost no danger either to people or to the environment. Complications may arise only in the cases of uncontrolled digging or drilling at the mound Therefore, drilling and earthworks are prohibited there and within the radius of 100m from it. In addition, the mound sections are covered with an up to 1.5 v deep layer of imported clean ground upon recommendation of experts from the All-Russian Scientific Research and Development Institute of Industrial Technology at Russia′s Atomic Ministry, which reduced radiation at the surface. Mound shielding with clean ground prevents direct contact of people with the radionuclides. It is recommended that an exclusion zone be temporarily maintained in the mound area with periodic monitoring of environmental entities.

***Kraton-3* site**: According to 1990 measurement data in, the radioactive fallout trace was detected up to 5km from the explosion epicentre, its width varied from of 0.5 to 2.5km, with a maximum gamma radiation level along the trace axis of up to 200 μR/h, and up to 730 μR/h at the epicentre (borehole mouth) of. Currently, the γ-radiation level within the recultivated territory amounts to an average of 30_50 μR/h.

Due to the fact that β-emitting radionuclide contamination of the soil and vegetation cover along a fallout trace with a length of up to 2 km is an additional radiation factor at the *Kraton-3* site, it is recommended that the sanitary protective zone be maintained in this sector with periodic radiation monitoring and limitation of the economic activity.

Pursuant to the resolution of the RSFSR Council of Ministers of 2 July 1991 No. IG-8-22991, a comprehensive expedition of the USSR Ministry of Public Health and the USSR Ministry of Atomic Power Industry worked at the *Kristall* and Kraton-3 sites in July and August 1991 which, pursuant to the programme of radioecological research, studied the influence of underground nuclear explosions on the radiation situation in the Mirnyy district of Yakutiya-Sakha and in 1991 carried out an investigation into the operating conditions of these sites by an interdepartmental committee The outcome of these efforts and appropriate suggestions were reported to the Council of Ministers of Yakutiya-Sakha and made known to the general public.

We should note in conclusion that rather rigid requirements were imposed on peaceful nuclear explosions [8–12]: fractures in the rock mass layers were not supposed to lead to an escape of radioactive products into underground water and on the earth′s surface; the explosions were conducted in areas removed from population centres and industrial and civilian structures so as to eliminate or significantly decrease the seismic effects on them; and various types of engineering and building designs were used to ensure the maximum possible stemming of boreholes and explosion product containment in the rock mass.

Main characteristics of underground nuclear explosions carried out in the region of the arctic circle for industrial purposes

Nos.	Explosion, date, region	Explosion purpose (customer)	Main parameters		Radiation consequences
			Depth, m	Yield, kt	
1	Globus-4; 02.07.71; Komi Autonomus SSR, 25 km southwest from town Vorkuta	Deep seismic sounding of the earth's crust for the purpose of searching for structures promising for mineral deposit exploration (USSR Geology Ministry)	540	< 3	Fully contained. Radiation situation at the natural background (NB).
2	Dnepr-1; 04.09.72; Murmansk region, 21 km from town Kirovsk to north-east	Ore fracturing at an apatite deposit ((USSR Fertilizer Ministry)	130	2.1	Fully contained. Radiation situation at the NB level.
3	Gorizont-2; 14.08.74; Yamalo-Nenets Autonomous Okrug, 190 km from village Tazovskiy to north-west	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	550	7.6	Fully contained. Radiation situation at the NB level.
4	Gorizont-1; 29.08.74; Komi AutonomusSSR, 60 km from town Vorkuta to west	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	590	7.6	Fully contained. Radiation situation at the NB level.
5	Kristall; 02.10.74 Yakutiya-Sakha, 90 km from village Aihal to north-east	Developing a tailing storage reservoir dam (USSR of Nonferrous metals Ministry)	100	< 2	At the mound area, mainly, from 15 to 30 μR/h, maximum – 54 μR/h (1991). Recultivation has been carried out. Sporadic radiation monitoring is being conducted.
6	Gorizont-4; 12.08.75; Yakutiya-Sakha, 120 km from town Tiksi to south-west.	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	500	7.6	Fully contained. Radiation situation at the NB level.
7	Gorizont-3; 29.09.75; Dolgano-Nenets Autonomous Okrug, 80 km from city Norilsk to north-east (Krasnoyarsk region, Russia).	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	830	7.6	Fully contained. Radiation situation at the NB level.

Nos.	Explosion, date, region	Explosion purpose (customer)	Main parameters		Radiation consequences
			Depth, m	Yield, kt	
8	Meteorit-2; 26.07.77; Dolgano-Nenets Autonomous Okrug, 80 km from city Norilsk to east(Krasnoyarsk region, Russia).	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	880	15	Fully contained. Radiation situation at the NB level.
9	Kraton-4; 09.08.78; Yakutiya-Sakha, 90 km from village Sangar to north-west.	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	560	22	Fully contained. Radiation situation at the NB level.
10	Kraton-3; 24.08.78; Yakutiya-Sakha, 120 km from village Aihal to south.	Deep seismic sounding of the earth's crust (Ministry of Geology of the USSR)	525	22	As the result of an unforeseen gas release, a radioactive fallout trace developed which was detected in 1990 for up to 5 km. The dose rate at the epicentre reached 1000 μR/h, on the trace – up to 200 μR/h (1991). The economic activity has been restricted. Periodic radiation monitoring is conducted in the sanitary-protective zone with a 2 km radius.
11	Kraton-2; 21.09.78; Krasnoyarskiy region, 95 km from town Igarka to south-west.	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	880	< 15	Fully contained. Radiation situation at the NB level .
12	Pirit; 25.05.81; Nenets Autonomous Okrug, 65 km from town Naryan-Mar to north-east.	Extinguishing the gas gusher (USSR Ministry of Geology)	1470	37.6	Fully contained. Radiation situation at the NB level.
13	Rift-1; 04.09.82; Dolgano-Nenets Autonomous Okrug, 190 km from town Dudinka to south-west(Krasnoyarsk region).	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	960	16	Fully contained. Radiation situation at the NB level.

Nos.	Explosion, date, region	Explosion purpose (customer)	Main parameters		Radiation consequences
			Depth, m	Yield, kt	
14	Dnepr-2; 27.08.84; Murmansk region, 21 km from town Kirovsk to north-east	Ore fracturing an apatite deposit (USSR Mineral Fertilisers Ministry)	160	Two explosi ons 1.7 kt each	Fully contained. Radiation situation at the NB level. Monitoring of the environment is performed.
15	Agat; 19.07.85;Arkhangelsk region, 150 km from town Mezen to west.	Deep seismic sounding of the earth's crust (USSRMinistry of Geology)	770	8.5	Fully contained. Radiation situation at the NB level.
16	Rubin-2; 22.08.88; Yamalo-Nenets Autonomous Okrug, 40 km from town Novy Urengoy to south-east.	Deep seismic sounding of the earth's crust (USSR Ministry of Geology)	830	15	Fully conained Radiation situation at the NB level.

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4.6. FAUNA OF NOVAYA ZEMLYA TODAY

S.M. Uspenskiy, G.V. Khakhin

It is known that secrecy and mystery cause increased interest in the object they cloak, and often provoke absurd rumours. The same happened to Novaya Zemlya. It is sufficient to remember the illegal penetration of Greenpeace activists here in autumn 1990.

Novaya Zemlya has been closed for almost forty years, but this is not the only reason why it attracts special attention. This is the largest archipelago in the European Arctic. The length of its islands is about one thousand kilometres, and their total area exceeds 90 thousand km^2, greater than that of Belgium and the Netherlands together. Arctic deserts and tundras are represented in their most typical forms. Perhaps no other arctic islands have such a variety of landscapes. The fauna of Novaya Zemlya is not very varied, but exceeds in its numbers those on other arctic islands. From time immemorial, Russian coast-dwellers have hunted and fished here, calling it the *mother*. Hence, the name Matochkin Shar – the strait between the islands Severny and Yuzhnyi (north and south) (*shar* is strait in the local dialect).

Hunting Novaya Zemlya fauna continued till the mid-fifties. In 1947, a State nature reserve was established here (the Novaya Zemlya part of the Seven Islands reserve). Later, traditional economic activity on the islands was terminated, the nature reserve was abandoned, and the North Test Site was founded. On the test site, nuclear explosions were detonated till 1963 in the atmosphere, and later underground, with contamination of the environment with radionuclides to various degrees.

What happened to Novaya Zemlya during these years, how have the consequences of long-term termination of hunting and simultaneous conduct of nuclear tests affect its natural environment and its fauna? Have all living beings been destroyed, and are the famous Novaya Zemlya bird colonies gone, as it was reported in the press? The preliminary answer to this question is given by the results of the expedition of All-Union Scientific Research Institute for Nature in summer 1992.

The first impressions are the strongest. On a small lake, some metres from the road along which cars run from the village to the airport and back, a couple of Bewick’s swans are sighted. According to their behaviour, they are near their nest. Above the crowded village Belushya bay, over its streets, and roofs of five-storey buildings, flocks of Bean geese and white-fronted geese fly low (completing their arrival in Novaya Zemlya). Barnacle geese, single and in couples, are seen even more frequently. Forty years ago these and other geese were somewhat rarer. As to the famous bird colonies, these large and sometimes enormous nesting areas of sea birds on cliffs are, perhaps, the main feature of Novaya Zemlya fauna. As a special survey has shown, at the end of the forties, on the west coast of the Yuzhnyi and Severnyi Islands, 46–47 bird colonies were located. Their main inhabitants were thick-billed murres (guillemot), whose total population reached about two millions [1, 2].

The work of the expedition of 1992 began with a brief survey of several bird colonies on Yuzhnyi Island from on board a ship. It was found that all colonies were preserved and had not suffered considerable changes. Great attention was paid to southern colonies on the south shore of Bezymyannaya bay, which extends here with small intervals to 11 km. These are the largest nesting areas on the islands with the most typical complex. Their main population is thick-billed murres, black-legged kittiwakes, black guillemots and common murres. Here are also nests of barnacle geese and snow buntings, which are not sea birds. These bird colonies were visited by the researchers most frequently. Information about them in literature goes back to the middle of the 19th century. From the mid-thirties, their systematic study began. In 1947–1950 they were a part of the nature reserve, and were the main object of stationary studies. From the mid-thirties, wide scale hunting was carried out here: collecting eggs and shooting birds. Some years, hunters collected over 250 000 murre eggs per year, which caused a sharp decrease in the number of birds nesting here. If in 1933–1934 there were over 1.5 million murres, by 1942 their number had dropped to half a million, and by 1948 to 200 000. The status of reserve favoured the recovery of the colonies. In 1950, the number of murres nesting here had increased to 240 000.

In 1992, the bird colonies occupied the same areas on rocks as before, and no indication of the presence of people, collection of eggs and bird hunting, at least for some preceding years, were found. The count performed in July 1992 and August 1994 recorded 280 000 murres nesting here, i. e. exceeding the level of 1950.

The increase in black-legged kittiwakes nesting here indicates that murre nesting areas separated, and free space appeared on rocks. First, black-legged kittiwakes nested in Bezymyannaya bay in the middle and the end of the thirties, when mass hunting of murres resulted in reduction of murre nesting areas. In 1948, here were 4500 nests of black-legged kittiwakes, in 1950 only 2800, but in 1992 already - 6500. As for the current state of the local murre population, it can be considered quite safe. In 1992, birds had normal weight, and the main periodic phenomena in their life took place in a routine manner.

Indigenous wild reindeer are also a feature of Novaya Zemlya. Their small dimensions, very light fur colour, and body build distinguish them from other reindeer as a special subspecies. By the beginning of the 20th century, reindeer on Novaya Zemlya were numerous and widely distributed. Judging from the number of skins exported, the number of reindeer in some years exceeded three thousand. However at the beginning of the twenties, their total number decreased drastically. The main reason was evidently frequent icy conditions and, as a consequence, mass death of these animals from hunger. Human population growth contributed to this process. Reindeer were not saved even by a hunting ban imposed in 1934. By 1950, their distribution was limited to some areas of the eastern shore of Severnyi island, and the total population was probably less than some tens animals [3]. As one of the rarest species of world fauna, the Novaya Zemlya reindeer has been included in Red Books not only of the USSR and Russian Federation but of the world (IUNP).

In 1928–1933, 604 domestic reindeer were brought from Kolguev Island to Novaya Zemlya, to the area of Gusinaya Zemlya, for breeding. However, reindeer-breeding did not succeed here, and the imported animals scattered over Yuzhnyi island. Also, it is possible that domestic reindeer have come to Novaya Zemlya by themselves across the frozen sea. One of the proofs for this is the presence of subcutaneous gadfly in Novaya Zemlya reindeer. The wild reindeer multiplied rapidly. At the end of 1979, their total population here was assessed as 10 000 [4, 5]. A survey of the habitats of wild reindeer on Novaya Zemlya in 1981 found that on Gusinaya Zemlya in early spring over 4000 reindeer died of hunger, of which about 70% were young animals. We noted deaths of reindeer in July 1992 in the region of Bezymyannaya bay, when we found 5–6 carcasses per km of the route, mainly of young animals. According to the findings of V.I.Zubko (1935) and V.D.Aleksandrova (1937) [6, 7], the reindeer capacity of winter pastures on Gusinaya Zemlya does not exceed 500–600 individuals. On the eastern coast of Yuzhnyi Island, winter pastures can feed about 4000 reindeer without damage to forage resources. According to these studies, the reindeer capacity of Yuzhnyi Island is about 5000 reindeer. Therefore, thorough control of the number and structure of this island reindeer population should be established, with consideration for the forage capacities of pastures. It is necessary to perform genetic research of the Novaya Zemlya reindeer to determine the status of this subspecies for the Red Book of Russia and IUNP, because the real situation with the indigenous reindeer on Novaya Zemlya remains unclear. It is possible that they have become completely extinct or have been absorbed by herds of wild reindeer, which are not directly related to the indigenous subspecies; nor do they have the status of specially protected animals, and so measures for their rational industrial usage should be developed.

Of the *Red Book* species, not only reindeer live (or lived) here. Novaya Zemlya is a maternity hospital for polar bears. On Severnyi Island, especially on its eastern coast, dens and the animals themselves were not rare even in the fifties, when the total population of the species decreased to a minimum. National and international measures for its protection had positive effects on Novaya Zemlya, too. The well-being of polar bears is favoured by the absence of human population on the greater part of the island. Bears have become common not only on Severny, but also on Yuzhnyi Island. They come to villages more and more frequently, where conflicts with people arise. This indicates the necessity for an appropriate strategy for controlling the bears.

The category of specially protected species included in Red Books of Russia and IUNP includes the Atlantic walrus living in coastal waters here. At times they were numerous and for a long time supplied Russian coast-dwellers with the most important or even the only object of hunting. By the middle of the 20th century, its population, like that of the polar bear, had decreased to a minimum. Very rarely, single walruses were seen off the coast of Yuzhnyi Island; more frequently they were seen in the northernmost parts of Novaya Zemlya, where their last two or three costal breeding-grounds were located. It is still not possible to be optimistic about the future of this species. However, regular appearances of single animals and small groups of them where they have not been seen for ages give reason for some hope. These places are the southwest and southeast of Yuzhnyi Island, and Matochkin Shar strait, where there has been an attempt to found a breeding-ground near the former village Lagernoye (in 1992, a group of 20–30 walruses lived here).

The *Red Book* species of Russian fauna also include Bewick's swan and the barnacle goose that live on Novaya Zemlya. According to survey information, the population of swans that come for nesting or for shedding feathers in the places of their greatest concentration (on Gusinaya Zemlya and Pankovaya Zemlya of Yuzhnyi island, and on Mezhusharskiy Island) has been stable in recent years. The west of Yuzhnyi island of Novaya Zemlya, along with Vaigach Island, is the eastern limit and the main habitat of barnacle geese in Eurasia. Even in the mid-fifties, their total population nesting here was assumed to be about one thousand couples only [3]. Their fate causes anxiety, and the species was included in the Red Book of the USSR. During the past years, the situation of this bird improved considerably. Barnacle geese have become common on the entire west of Yuzhnyi island (at least 10–30 couples nest in Bezymyannaya bay), and in the south of Severnyi island (in particular, in Krestovaya bay). This is confirmed by the results of bird counts in their wintering places in Western Europe. At the end of the eighties, the population of this bird was determined to be 70 thousand there.

The discussion of specially protected animals living on Novaya Zemlya and in its coastal waters will be concluded with the bowhead whale. (The peregrine and enigmatic arctic narwhal should also be included; however, we do not have data about their numbers.) No other animal is so valuable for industrial use as the bowhead whale. Its weight can reach 150 t and its body length over 20 m. One whale can yield over 30 t of fat (the amount that can be obtained from 3000 pigs or 6000 sheep). This fat is valuable not only for technical use, but for food consumption as well. A whale can also provide dozens of tons of meat, highly valuable baleen and many other materials. The Barents Sea once abounded in these giants, and hundreds of whaling ships came here for hunting. Whale hunting flourished in the 17th century. In the next century, the hunting of whales in the Barents Sea considerably decreased, though in some years thousands of whales were killed. In 1905, 600 whales were killed in the Barents Sea; in 1912 only five. In the 1920s, bowhead whales in this part of the arctic were considered completely extinct. Only old gigantic bones on the shores of Novaya Zemlya were a reminder of their former abundance. However, in recent years, a slight hope for restoration of this species appeared. In the 1980s, a small group was found by the expedition of the All-Union Scientific Research Institute for Nature in the waters of Franz Joseph Land. Later, reports of seeing these animals came from the region of Novaya Zemlya. These data are contradictory, and require further analysis and attention.

The positive effect of terminating hunting of industrially valuable threatened species by placing them under special protection is obvious. However, the influence of nuclear explosions on the local natural complexes has been studied insufficiently. Here we do not touch the complex and difficult problem of whether nuclear tests are permissible on Novaya Zemlya at all. We can only note that radioactivity recorded during the period of work of the expedition in Bezymyannaya bay did not exceed background levels, and the concentration of dangerous radionuclides was considerably below permissible levels. We analysed murres, their separate organs, food, and mountain rock, soil and vegetation in the vicinity of the bird colonies. It is also known that the level of radioactive contamination on Novaya Zemlya by the beginning of the 1970s approached the current level [8]. Thus, both the direct (at the moment of an explosion), and the subsequent influence of this factor (action of radioactive fallout) has been observed on Novaya Zemlya and in adjacent regions for over 20 years. We have found some reduction in the number of thick-billed murres that nest in the bird colonies in comparison to 1950. However, this *deficit* can hardly be attributed to nuclear tests. The decrease in the number of murres in the 1980s was noted in some other parts of the Barents sea coast also (in particular, in the north of Norway). The decline of food capacity of bird habitats played a role here.

Until the mid-1950s, 10 hunter`s villages and over 50 areas with residential houses were located on Novaya Zemlya, with a population of about 400. The main object of local hunting was arctic fox (in some years 5000-6000 arctic foxes were killed here). Hunting sea animals: harbour seal, bearded seal, harp seal, white whale and, earlier, walrus also played an important role for local hunters. Hunting wild reindeer was also noticeable on these islands. Novaya Zemlya was the main region in the USSR for collecting loon down. The amount of it collected annually reached three tons. Fishing loach (a salmon species) and cod, collection of eggs and hunting birds in bird colonies were developed here. Novaya Zemlya was famous for an abundance of geese. A large peninsula here has the name Gusinaya Zemlya (the goose land).

The resources of Novaya Zemlya fauna can and must be used. . There is not only reindeer hunting, and fishing for local needs. Employees of polar stations and other amateur hunters hunt arctic foxes. However, the main hunting of these animals takes place during their autumn–winter migrations on Vaigach Island and the mainland tundras. The success of breeding geese on Novaya Zemlya is important for hunters in large areas of Russia and Western Europe, for which Novaya Zemlya is a reserve that enriches hunting areas outside its boundaries. Therefore, it is necessary to have rational hunting on Novaya Zemlya, including hunting in loon nesting areas, with the necessary complex of biotechnical measures. The question of who must do it and how is still unanswered

The increased instability and vulnerability of the arctic nature complexes due to the impact of human activity, the concentration of species and populations of rare and almost extinct animals and plants, and the efficiency of Arctic reserves as a means of stabilizing local ecosystems makes it vital to organize a network of specially protected areas in this region, on land and in the sea. This is true for Novaya Zemlya, where the reserve that existed at the end of the 1940s has demonstrated great efficiency. In spite of its modest possibilities, serious scientific research was performed there, the results published, systematic monitoring was begun, and the regime of the reserve favoured considerable increase in the number of birds, the main objects of protection.

The role of this reserve in the study and protection of local ecosystems, and the necessity for its restoration was frequently noted in the literature. This reserve is included in the draft for the geographic network of the USSR reserves developed by the Academy of Sciences [9], in the plan for organizing reserves in the USSR [10], and in the project for the creation of standard reserves in the Russian Federation [11]. When Novaya Zemlya was turned into the North Test Site, the expediency of recreating the reserve here increased. It could be used for restorating systematic environmental observations as a complement to existing medical and radiological studies, whose topicality goes far beyond the interests of the test site. We have noted above the model character of the Novaya Zemlya ecosystems, the presence of unique natural objects. The features of antropogenic impact on the nature complexes here attract great attention of researchers (in zoology, ecology) from the USSR and abroad. The reserve could be a good basis for the reception of such persons.

The final decision on the territory of the Novaya Zemlya reserve, its regime, and a research programme requires additional study. The reserve should include Gribovaya bay and Bezymyannaya bay (formerly part of the *Seven Islands* reserve). Probably, it should also include a part of the eastern coast of Severny Island as the possible habitat of indigenous reindeer and the location of polar bear reproduction.

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4.7. SAFETY OF UNDERGROUND NUCLEAR TESTS AT THE NORTHERN (NOVAYA ZEMLYA)

Answers by Russian experts to questions on the safety of underground nuclear tests at the Northern (Novaya Zemlya) Test Site asked by Norwegian experts J. Skorve and J. K. Skogan in *The NUPI Satellite Study of the Northern Underground Nuclear Test Area on Novaya Zemlya* [1]

The answers have been prepared by the specialists of an inter-department expert commission on assessment of radiation and seismic safety of underground nuclear tests: Prof. A. M. Matushchenko (co-chairman of the indicated Commission), K. V. Kharitonov (Minatom of Russia), Ph. D. V. G. Safronov (Ministry of Defence of Russia), V. F. Dorodnov, Ye. P. Kozlov, A. I. Kurkin (the All-Russian scientific-research and design institute for industrial technology), A. K. Chernyshov (the Russian Federal Nuclear Centre, the All-Russian scientific-research institute of experimental physics), Doctor of Chemistry Yu. V. Dubasov (scientific-production association “Khlopin Radium Institute”, Doctor of Physics and Mathematics V. V. Adushkin, Ph. D. V.I. Kulikov (the Institute of dynamics of geospheres of the Russian Academy of Sciences), and invited experts Ph. D. V. G. Spungin (the Institute of dynamics of geospheres of the Russian Academy of Sciences), A. N. Titkov (the All-Russian scientific-research and design institute for industrial technology), and I. I. Petrozhitsky (the 36th party of the tenth expedition of the enterprise "Hydrospetsgeology").

In the NUPI report, questions were posed about the safety of nuclear tests at the North Test Site. Some were answered in an Issue 1 of Reference Information published in October 1992 [2]. These questions are undoubtedly pertinent. It was shown that the adopted requirements and standards of the safety of tests in horizontal tunnels and vertical boreholes were observed, with regard to the 1963 *Moscow Treaty*.

The 39 underground nuclear tests at the North Test Site are defined according to the radiation situation they created: 12 explosions with almost complete localization of radioactive products in the rock massif; 25 explosions accompanied by releases of radioactive noble gases into the atmosphere but without contamination of the territory of the test site; two explosions accompanied by accidental releases of gaseous and volatile products (which determined these tests for their direct participants as non-standard radiation situations).

The questions asked by the Norwegian experts also relate to the post-explosion and long-term state of the zones of localization of long-lived radionuclides in the massif with consideration for the impact on them of hydrogeological conditions on Novaya Zemlya. In response, we describe the processes that determine the phenomenology of development of a contained underground nuclear explosion with formation of radioactive contamination of rock, to link the questions of providing safety of such explosions in the geological formations of Novaya Zemlya with consideration for their hydrology.

The principal conditions of localization of radionuclides of an underground nuclear explosion are already determined at the stage of formation of the evaporation zone and formation of the initial cavity, whose walls are covered with a layer of melted rock 7–10 cm thick, containing up to 90% of the radionuclides, which, being refractory and weakly volatile, are vitrified in the explosion cavity in the bulk of the melted rock with the total mass up to 800–1000 t/kt (i. e., $C_{fission} < 10^{-4}$ and $C_{Pu} \sim (2 \cdot 10^{-8} - 2 \cdot 10^{-9})$ Ci/g).

During the process of rock falling into the cavity and forming the chimney, the components of the gas and steam mixture contact relatively cold surfaces of rock fragments. From this moment, the processes of mass transfer control the radioactive contamination of rock in the chimney. One may assume that when the rock fragments fall into the cooling melt, gas and vapour that come out through the chimney are being cooled very quickly, coming into contact with the fragments, and propagation of gaseous products along artificial cracks created by the explosion begin from the moment of desealing the cavity and continues to the end of formation of the chimney. The composition of the gas and vapour mixture during this period will be determined mainly by the most volatile components from the rock surrounding the nuclear charge. In the majority of experiments, such components are water vapours and carbon dioxide, which carry the radionuclides (~ 10%) through the chimney.

The moment of cavity desealing depends mainly on the physical properties of the enclosing rock, its ability to resist to the impact of external factors (the processes in the central zone), the preshot joint sets and some other factors. In the majority of experiments, the beginning of the cavity collapse was recorded less than a minute after the detonation, and sometimes continued for a few minutes. In a number of experiments, the time of the beginning of the chimney formation took some hours, but cases are known when the collapse of the cavity roof took place several days or months after the detonation.

Naturally, the massif jointing before and after the explosion is of great importance for penetration of steam and gas mixture in the chimney. There are sufficiently universal dependencies for assessment of dimensions of the fracture zones normalized to the value of the cavity radius (R_0), in particular:

— the height of the fracture zone above the point of the nuclear charge emplacement – (4–5)R_0;

— the depth of the fracture zone below the point of the nuclear charge emplacement – (2–2.5)R_0;

— the radial length of cracks along the horizontal – (2.5–3.5)R_0.

The total volume of voids in the zone of artificial fractures created by an explosion has been calculated:

$$V_{\Sigma} = \sum_{i=1}^{n} v_i \cdot \Phi_i ,$$

where Φ_i is the porosity of the i-th zone, v_i is the volume of the i-th zone, n is the number of the zones. This volume determines the redistribution in the massif of medium- and strongly-volatile radionuclides non-captured by the melt, which are the decay products of gaseous predecessors (^{89}Sr, ^{90}Sr, ^{137}Cs) or with their own volatility or the volatility of their predecessors (^{103}Ru, ^{106}Ru, ^{141}Ce).

This process is also sufficiently well studied, which permits assessment of the dimensions of the *halos* of distribution of radionuclides in the direction to the earth`s surface (to the hypocentre). It is clear from this that when assessing the safety of underground nuclear tests on Novaya Zemlya and at other locations, it is necessary to have extensive information about the geological structures in which explosions are conducted in order to assess the post-explosion processes that determine the degree and regimes of localization of various radionuclides in the rock massif.

We share the desire of the Norwegian experts to know the answers to important questions about the conditions of underground nuclear tests on Novaya Zemlya. Below we present our comments (answers) to the questions posed in the NUPI report`s about the safety measures at underground nuclear tests in the geological formations on Novaya Zemlya in the order of their presentation.

1) In which geological structures have the nuclear detonations taken place?

The Novaya Zemlya archipelago, Vaigach island and the mainland ridge Paikhoi form a separate fold system, consisting mainly of Palaeozoic rock. The system was formed on a pre-Palaeozoic basis, and high-intensity folding processes in it were concluded at the beginning of the Triassic period. As for the rock composition — its age, the degree of metamorphism and the corresponding geotechnical properties, the geological formations of Paikhoi — the Novaya Zemlya fold system differs considerably from the more ancient and stronger metamorphosed formations of the northern coast of the mainland — the Kola peninsula, Lapland, and the Urals.

In the geological structure of the Novaya Zemlya islands, Palaeozoic depositions are present, covered with thin cover of Quaternary formations. Only small areas of the Severny Island display outcrops of more ancient rock of pre-Palaeozoic basis. Palaeozoic pre-Perm depositions are represented mainly by terrigenic rock (sandrock, clay shale) and, to a lesser extent, by carbonate rock (limestone, dolomite) widely distributed at the southernmost of Yuzhnyi island, and playing a considerable role in the geological section of the *Mosaic* region in the northernmost of Yuzhnyi Island. The Perm terrigenic rock (sandrock, clay shale) is mostly found on Yuzhnyi Island and, to a lesser extent, on Severny Island. The total thickness of the Palaeozoic depositions reaches 10–12 km. Mesozoic, Palaeogenic and Neogenic sediment is absent on the archipelago.

The thickness of loose depositions generally does not exceed 50 metres, and can considerably increase on the bottom of large river valleys located along ancient tectonic disruptions and filled with clay and large-fragment products of upper-Quaternary sea transgressions.

All rock forming the archipelago carries traces of current tectonic activity. The main directions of disruptions coincide with stratification of rock, or disruptions are located under an angle to the stratification or across the strike, forming block structures in the massif. This excludes the appearance, as a result of an underground nuclear explosion, of various deformations that cause unpredictable radiation releases.

The region for testing underground nuclear explosions is composed of hard rock, mostly shale, quartzite, sandstone and limestone. From the surface, the rock is pierced with a thick set of weathering cracks that penetrate to the depth of 4–5 m. Below this — down to 100 m — cracks are practically absent, excluding tectonic disruptions and the fracturing zones accompanying them. The pitch angle reaches 40–60^{o}.

The average physical and mechanical properties of the rock are: density – 2.7 g/cm^3 (shale, sandstone); compressive strength – 100–150 MPa (sandstone), –50 MPa (shale); moisture content – 1%, gas content at heating up to 1000 ^{o}C – up to 4% (sandstone), 8–15% (shale). Down to 600 m, all the indicated rock is in the long-term permafrost state. Figure 4. present a typical plot of a horizontal tunnel, which clearly illustrates the geological structure in which a underground nuclear explosion was detonated.

The geological formation of the Novaya Zemlya archipelago belongs to practically aseismic regions. Tectonic ruptures at the bottom of the Barents and Kara seas are related to rift formations of ocean mountain systems. No underwater disruptions have been found in the areas directly adjacent to the Novaya Zemlya islands. The presented materials are given in detail in papers [3] and [4].

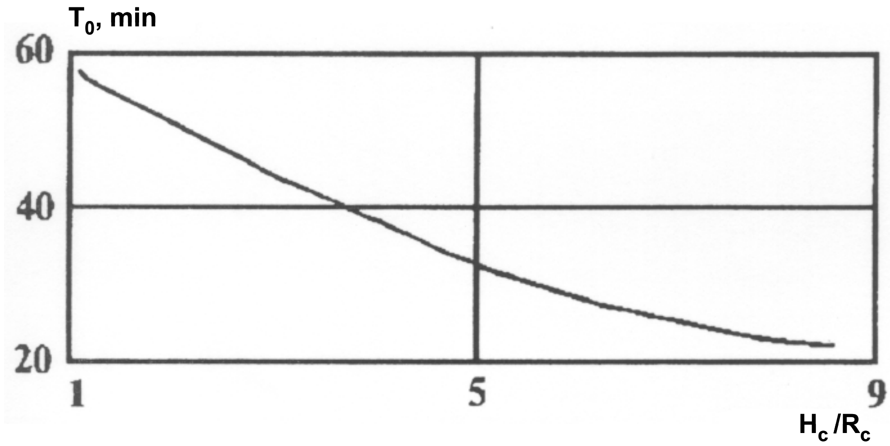

FIG. 28. Dependence of the time of beginning of radioactive gases release on the height of the "nuclear chimney.

2) With regard to radioactive containment, to what degree have post-explosion cavities been damaged by cracks and the delayed collapse of the chimneys above?

At an underground nuclear explosion, the time of appearance of explosion gases in the atmosphere (T_0) depends on the parameters of the chimney formed as result of the cavity collapse with the radius (R_c), whose height (H_c) is determined by physical and chemical properties of the rock (see Fig. 28.).

As stated above, at the moment of the cavity collapse, over 90% of radioactive products have been concentrated and fixed in the melt. With transition to the explosion in the weaker rocks, the dependence of the release of gaseous explosion products on the parameters of the cavity collapse is even stronger. For Novaya Zemlya, this determined the time of the beginning of gas release to the atmosphere (T_0) within 10–60 min at $\overline{H}$ ~ 90–120 m/kt$^{1/3}$.

Formation of the nuclear chimney influences not only T_0, but the intensity of release of explosion gases into the atmosphere and, naturally, the decrease of the collapse time causes an increase of intensity of the release, i. e. an increase of the amount of gas released into the atmosphere at a given moment. RNG seepage into the atmosphere took place at 27 underground nuclear explosions, and only 2.5–5 kCi of the daughter ^{137}Cs was formed in the atmosphere at that time.

3) Also with regard to radioactive containment, to what degree have high yield explosions damaged older detonation cavities close by?

On the whole, severe damage can be assessed by the value of the maximum mass velocity in the ground shock wave 5–10 m/s and, correspondingly, by the value of compression stress of about 1000 kg/cm^2 (these values are occurred at distances of 60–70 m/kt$^{1/3}$).

However, from the viewpoint of localization of the explosion products, this process is not considered unfavourable: moreover, it promotes (and accounts for) the reduce of the initial gas pressure and increase of heat exchange intensity due to redistribution of gaseous products in the developed system of cracks. The method of such abrupt reduce of gas pressure in the cavity and the change of the direction of gaseous products motion in the massif to the zone of rock disrupted by previous explosions provided localization of products due to increase of T_0 (according to attributes of novelty and usefulness this method is protected by copyright and is regarded as *know-how*).

4) How serious are the problems with radionuclides leaking from the explosion cavities and into the groundwater ?

Long-term observation of water in horizontal tunnels has shown that such a problem does not exist on Novaya Zemlya. In the long-term permafrost rock, in which these tunnels were driven, underground water is absent, and the rock itself is not water-saturated.

Studies performed at drilling of vertical boreholes also indicate the absence of groundwater below the permafrost zone. Also, as noted, at underground nuclear explosions about 90% of radioactive products are solidly vitrified in the rock melt, and only about 10% is in the fracture zone and in the chimney. However, they are not subjected to the action of water flow, because infiltration of atmospheric precipitation in the massif disrupted by an explosion is absent.

Concentration of radioactive explosion products in the melt is below 10^{-4} Ci/g, and concentration of long-lived actinides (mainly of plutonium) is at the level of $2 \cdot 10^{-8}$–$2 \cdot 10^{-9}$ Ci/g. An important factor is also the low leaching of radionuclides from the melt. Direct experiments have shown that it is at the level of 10^{-5} - 10^{-7} g/cm$^2\cdot$day, and the calculation assessments show that even direct contact of the melt with water will cause radionuclide concentration in underground water by many orders of magnitude below the adopted international standards for permissible radioactive contamination of water.

5) What kind of observations have been made of the effects and the damage caused by the heat front from an underground nuclear explosion, on the permafrost layer above the explosion cavity ?

These effects, disruptions and processes were studied on the basis of calculations of dynamics of heating of perennial permafrost rock around underground nuclear explosion cavities of various yields. For conditions on Novaya Zemlya, it was assessed that the thawing zones with release of groundwater do not go beyond the zones of radial fractures in the rock massif disrupted by an explosion (on average, the ratio of the thawing zone to the explosion depth is about 0.5.) Fig. 6 presents examples of such assessments for underground nuclear explosions of various yields (up to 150 kt).

Experimental studies of the effects by drilling to the indicated zones were not necessary because regular hydrogeological observations were performed in the tunnels. No water was present after explosions, and the tunnels remained dry for a long time.

6) Have the Russians drilled monitoring wells to determine to what degree radionuclides are transported with the groundwater to the Matochkin Shar and the Shumilikha valley floor?

Such boreholes have been drilled, and they were of dual purpose: for reconnaissance and observation. In particular, one of the boreholes was drilled to a depth of 500m in the Shumilikha river valley, and underground water was absent there. The absence of underground water in the explosion region made special observation of filtration of radionuclides from the zones of underground nuclear explosion cavities and chimneys unnecessary.

However, we now recognize the expediency of using (reactivation) available boreholes and drilling two or three new ones for observation on the coast of the Matochkin Shar strait, with the purpose of objective confirmation of the absence of migration of radionuclides from the explosion zones over time. It is possible that the information obtained at these boreholes may be transferred to the interested parties within the frame of corresponding agreements.

7) With regard to safety, why have several high yield nuclear underground detonations taken place only 1.8–3.5 km from the main base of Sevemy?

The regime of tests was determined by the adopted programme, whose realization was performed with consideration for radiation and seismic safety criteria for underground nuclear explosions detonated 2–5 km from Severny. Also, during these underground nuclear explosions Severny had only one-storey wooden houses, which received almost no damage. The danger of radiation impact was also excluded by preliminary evacuation of the staff there.

8) Three major post 1942 craters have been found and identified as likely subsidence craters, and two other possible craters have also been located. With regard to the cratering and the possibility of leakage of radionuclides into the groundwater, at what depths have the nuclear "devices been detonated?

Formation of collapse craters in the epicentral zones of underground nuclear explosions in the rock of different lithological composition is a regular and forecastable phenomenon. Their formation took place at some explosions on Novaya Zemlya. Norwegian experts monitoring Novaya Zemlya using satellite observation found split and collapse craters identified as the effects of the following tests with explosions of nuclear devices at the depths of 400–650 m: No. 1 (Fig. 15 of the NUPI report, page 28) – UNE "A-16" (28 June 1972); No. 2 – UNE "A-4" (21 October 1967) and No. 3 – UNE "A-1" (27 October 1966); collapse craters No. 4 does not exist (probably it is photo defect).

The possibility of leakage of radionuclides to groundwater in these specific cases, as noted earlier, is excluded in connection with the absence in conditions of Novaya Zemlya of infiltration of atmospheric moisture to the massif. After explosions, all indicated tunnels have been dry to date, without water at their portal tunnel areas.

9) With regard to possible nuclear contamination of the groundwater and the fact that the Shumilikha river freezes up completely during the winter, where is the drinking water taken from during the winter season, and where are the sources of the industrial water used in activities at the nuclear test site ?

Drinking water during all seasons is taken from a specially constructed reservoir located at the foot of the Lazarev mountain. The water quality after proper processing meets the adopted standards, including international ones. For technical purposes, water accumulated in reservoirs constructed near each object is taken.

10) Was any water hit during tunnelling activities on the underground nuclear test site? An overview of this is important because it gives 3-D information on where in the permafrost water is found.

All tunnels were in perennial permafrost rock. Neither hit nor filtration of groundwater occurred during their construction. Currently, all the tunnels are dry.

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4.8. RADIOACTIVITY OF WATER IN THE BARENTS AND KARA SEAS

K.G. Vasilyev, Yu.V. Dubasov, V.G. Safronov, A.F. Tkachenko, V.I. Filippovsky, V.V. Chugunov

The radioactivity of sea water, bottom depositions, and the sea flora and fauna is determined by their content of natural and artificial radionuclides. Natural radionuclides can be of terrestrial and space origin. The main sources of artificial radionuclides that contaminate the sea are test explosions of nuclear weapons and dumping in the sea of radioactive waste produced by ships with nuclear power engines.

Currently, with relatively low global contamination of the hydrosphere, natural radionuclides mask the presence of artificial radionuclides in sea water. This hinders detection of artificial radionuclides within routine radiometric techniques. Therefore, any partial or complete radiological and hygienic survey or conclusion on the radiation situation in zones with a low level of contamination must consider the contribution of natural radionuclides to the total radioactivity of the medium under study.

Sea water contains practically all known natural radionuclides. Table IX [1] presents concentrations of the principal radionuclides in the water of the world's oceans and in water specific activities.

Table X [1] gives average values for activities of the main transuranic elements in the sea water and bottom sediments in the northern hemisphere. For comparison, the same table gives average activities of natural actinides.

TABLE IX. RADIOACTIVITY OF WATER IN THE OPEN SEA

Radionuclides	Decay type	Decay half-period, years	Concentration, g/l	Volumetric activity, Bq/m^3
Potassium-40	β^- (89%)	$1.31 \cdot 10^9$	$4.5 \cdot 10^{-5}$	$1.3 \cdot 10^4$
Rubidium-87	β^-	$6.15 \cdot 10^{10}$	$8.4 \cdot 10^{-5}$	$2.2 \cdot 10^2$
Uranium-238	α	$4.5 \cdot 10^9$	$2.0 \cdot 10^{-6}$	$1.0 \cdot 10^2$ *
Uranium-235	α	$7.1 \cdot 10^8$	$1.5 \cdot 10^{-8}$	3.0 *
Thorium-232	α	$1.41 \cdot 10^{10}$	$1 \cdot 10^{-8}$	0.2 *
Radium-226	α	$1.6 \cdot 10^3$	$3 \cdot 10^{-13}$	30 *
Carbon-14	β^-	$5.73 \cdot 10^3$	$4 \cdot 10^{-14}$	7
Tritium	β^-	12.3	$8 \cdot 10^{-17}$	25 **

* Activity of radionuclide with its daughter products.

** Only in upper layer 50–100 m thick.

TABLE X. TYPICAL CONCENTRATIONS OF ACTINIDES IN SEA WATER AND BOTTOM SEDIMENTS

Radionuclide	Decay half-period, years	Sea water, Bq/m^3	Bottom sediments, Bq/kg
Artificial			
Pu-238	87.7	$5.9 \cdot 10^{-4}$	$1.7 \cdot 10^{-2}$
Pu-239	$2.4 \cdot 10^{4}$	$8.0 \cdot 10^{-3}$	0.25
Pu-240	$6.6 \cdot 10^{3}$	$5.0 \cdot 10^{-3}$	0.16
Pu-241	14.4	$6.5 \cdot 10^{-2}$	2.0
Am-241	433	$1.6 \cdot 10^{-3}$	0.2
Np-237	$2.1 \cdot 10^{6}$	$1.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
Cm-244	18.1	$2.0 \cdot 10^{-7}$	$2.5 \cdot 10^{-5}$
Natural			
Ac-227	21.6	$4.1 \cdot 10^{-3}$	16
Pa-231	$3.4 \cdot 10^{4}$	$4.1 \cdot 10^{-3}$	17
U-235	$7.1 \cdot 10^{8}$	1.85	0.6
Th-230	$7.5 \cdot 10^{4}$	$1.5 \cdot 10^{-2}$	150
Th-234	24.1 days	37	12
U-238	$4.5 \cdot 10^{9}$	37	11
U-228	1.9	$7.4 \cdot 10^{-2}$	21
Th-232	$1.4 \cdot 10^{10}$	$4.1 \cdot 10^{-3}$	20
U-234	$2.5 \cdot 10^{5}$	44	18

One can see from the data of Table XI that beta activity of the ocean water is determined mainly by the content of potassium-40, and is approximately $1.35 \cdot 10^{4}$ Bq/m^3. Contributions of other radionuclides to the total water activity are negligible.

Alpha activity of water is determined mainly by the content of uranium, thorium-234 and radium-226, and is approximately 120 Bq/m^3 [1].

The level of water radioactivity in the open sea is, as a rule, direct related to its salinity. The relation between salt content of the inner or coastal regions of peripheral seas is not constant and can considerably vary under the influence of river run-off, processes of ice melting and formation etc.

Salinity of the water in the Barents Sea is close to oceanic concentration, and does not vary much. Table XI [1] presents the average content of the principal radioactive elements in its water.

TABLE XI. RADIOACTIVITY OF WATER IN THE BARENTS SEA

Element	Concentration, g/l	Volumetric activity, Bq/m^3
Potassium	0.35	$1.3 \cdot 10^4$
Rubidium	$3 \cdot 10^{-4}$	200
Uranium	$1.3 \cdot 10^{-6}$	32
Thorium	$5 \cdot 10^{-9}$	$6.3 \cdot 10^{-2}$
Radium	$3.5 \cdot 10^{-13}$	13

High salinity is observed also in the western part of the Kara Sea, which has almost no river run-off. The volumetric beta activity of water in this region is $(1.1 \pm 0.07) \cdot 10^4$ Bq/m^3 [1].

Bottom depositions in the majority of cases are contaminated via water, in which a number of physical and chemical processes take place that favour or hinder contamination of grounds. When radioactive substances enter the sea or fresh water, precipitation, sorption and dilution of the substances take place, with formation of colloids and complex compounds and other processes.

The degree of radioactivity of bottom depositions depends partly on their stratification and type. It has been found that the surface layers of bottom depositions, as a rule, have a higher content of potassium and uranium than the underlying ones. In all cases, potassium-40 is the main source of natural beta activity, and uranium and radium are the main sources of natural alpha activity, in bottom depositions.

In silts of the Barents and Kara seas, the potassium content reaches 3%, and beta activity is $(7.4–11) \cdot 10^5$ Bq/m^3 [1]. Such high potassium concentrations are present mainly in the bottom sediment with high density of animal and plant organisms.

Artificial radionuclides are also constantly present in the water of the world's oceans. These include relatively long-lived and biologically dangerous ^{90}Sr and ^{137}Cs. Concentrations of these radionuclides in the surface layers of open sea water are, on the average, 3.7–18 Bq/m^3 [1].

Radionuclides that are uranium decay products have their own specific features in distribution between water, bottom sediment and water organisms. Thus, strontium is distributed comparatively homogeneously between these substrates. Caesium is accumulated mainly in the ground, and cerium mainly in biomass. In this connection, the lowest accumulation factor in bottom depositions is typical for strontium (1–1.5), and the highest for caesium (10–25). Cerium has intermediate value (8–10). It has been found that over 90% of the entire activity is accumulated in the upper centimeter of bottom depositions.

Nuclear tests carried out by the USA, Great Britain and the USSR before 1963 in the atmosphere, on the ground and on the water are the main sources of global contamination with artificial radionuclides. The last nuclear explosion in the atmosphere was detonated by China in October 1980. During the entire period of nuclear tests in the atmosphere (1945–1980), $9.6 \cdot 10^{17}$ Bq of ^{137}Cs was emitted into the environment (without consideration for its decay). Currently, the amount of this main dose-forming gamma-emitting radionuclide in the atmosphere, the ocean, on the ground and in biological ecosystems has decreased to $5 \cdot 10^{17}$ Bq due to radioactive decay (without consideration for the release as a result of the Chernobyl accident).

The density of artificial radionuclide contamination of the earth's surface, including the hydrosphere, mainly with ^{90}Sr and ^{137}Cs grew rapidly during the period of a large series of tests in 1955–1958 and 1961–1962, and reached a peak by 1966. Figures 29 and 30 show the dynamics of contamination of salt and fresh water near and on Novaya Zemlya.

Radiation and hygienic surveys of the environment on the Novaya Zemlya archipelago started almost immediately after the beginning of operation of the nuclear test site. Some of them were systematic, performed within scientific research programmes of the Ministry of Defence and the State Committee for Hydrometeorology; others were performed within expedition programmes before and after each explosion.

It is seen from the data on the activity of sea and drinking water in separate regions of the archipelago in 1955-1965 (see Figs. 29 and 30) that during that period the volumetric activity of drinking water (from sources in Belushya and Rogachevo villages and in the region of Mityushikha and Chernaya bays) was below the adopted permissible levels and did not exceed the natural background level. At the same time, radioactive contamination of sea water and bottom sediment directly in the test region stayed comparatively high. Thus, in Chernaya bay, stable contamination of the ground, algae and bottom organisms occurred. Table XII presents the data on radioactive contamination in Chernaya Bay and in the seas adjacent to the archipelago.

TABLE XII. RADIOACTIVE CONTAMINATION OF NOVAYA ZEMLYA COASTAL WATERS (ON THE BASIS OF SURVEYS OF 1959)

Region of survey	Water volumetric activity, kBq/m^3	Specific and surface activities of bottom depositions	
		Bq/kg	kBq/m^2
Chernaya Bay	3.7	$2.6 \cdot 10^5$	$3.1 \cdot 10^3$
Barents Sea	4.8	$1.4 \cdot 10^3$	17
Kara Sea	4.4	$1.5 \cdot 10^3$	18

The levels of radioactive contamination of bottom depositions in the Barents and Kara seas are within the limits of variation of natural radioactivity. The degree of contamination decreases in time due to radioactive decay and leaching. By now, the activity of bottom ground must have decreased two–threefold, and the water volumetric activity must correspond to the natural background.

Complex investigations performed in 1963–1988 on Novaya Zemlya have shown that concentrations of ^{90}Sr, ^{137}Cs and tritium in water are at least 100 times below the permissible levels set for drinking water [2]. Increased concentrations of these radionuclides were recorded in some areas of the nuclear tests. Thus, concentrations of ^{90}Sr and ^{137}Cs in the water of the river Sakhanina (the region of Chernaya Bay) in 1978 were 5.2 and 7.0 kBq/m^3, respectively. Concentrations of tritium in the right tributary of the river Shumilikha was $1.7 \cdot 10^4$ kBq/m^3, and in the drinking water of Severnyvillage was $3.7 \cdot 10^3$ kBq/m^3. It should be noted that high concentrations of tritium (soft beta-emitter) in streams and lakes in the region of the Matochkin Shar strait can be observed for a long time because of washing them out from tritium saturated mountain massifs.

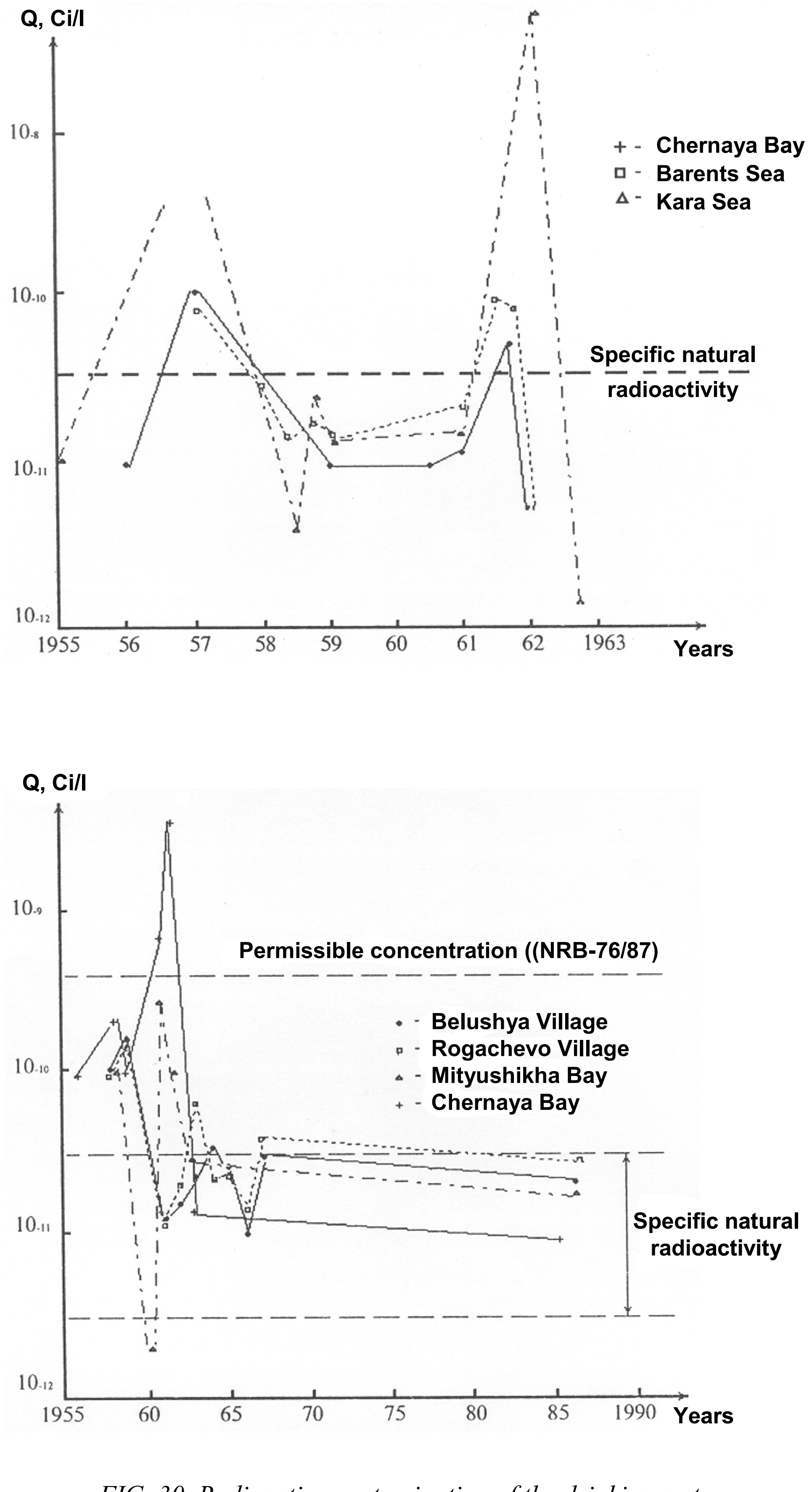

FIG. 30. Radioactive contamination of the drinking water.

The highest ^{90}Sr concentration in the water of some rivers in the polar region was recorded in 1963–1965. The maximum value, for example, in the river Pechora in 1965 was 45–90 kBq/m^3, which is by two orders of magnitude lower than the permissible level [3].

From 1964, only underground tests were performed at the North Test Site (42 underground nuclear explosions), at 25 of them only radioactive noble gases entered into the atmosphere. The total amount of ^{137}Cs formed in the atmosphere after them is assessed at $(9.2\text{-}18.5)\cdot 10^{13}$ kBq, whereas after the Chernobyl accident about $5\cdot 10^{16}$ kBq of ^{137}Cs was deposited on the territory of our country only. As a rule, ^{90}Sr does not appear in the atmosphere at such tests. Thus, underground nuclear tests on the Novaya Zemlya archipelago made no noticeable contribution to radioactive contamination of the environment, including sea water.

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4.9. CRITERIA OF INCREASED ENVIRONMENTAL SAFETY AT UNDERGROUND NUCLEAR TESTS

L.F. Belovodsky, Yu.V. Dubasov, A.S. Krivokhatsky, A.M. Matushchenko, K.V. Kharitonov, A.K. Chernyshov

The first issue of *Nuclear explosions in the USSR. The North Test Site* (1992) presents criteria for radiation and seismic safety of underground nuclear explosions detonated during the test period. (pp 38, 131). However, since the publication of this material, increased requirements and criteria have been formulated for the environmental safety of the tests and have received official approval. They are presented here as evidence of continuing efforts to improve the safety of personnel and population when the tests were restarted at the North Test Site.

A thorough expert analysis is performed before a nuclear test, taking into account not only standard conditions expected at an underground nuclear explosion, but also possible accidental situations, for which radioactive and chemical releases, possible actions of the personnel, methods of warning etc. are assessed. For that, three typical zones (areas on the surface) are assessed:

— 10 km in radius – presence of a limited number of personnel to control the experiment and measure the parameters of the explosion;

— 30 km in radius –test site boundary; and

— 200 km in radius – nearest location of population residence.

The principal underground nuclear explosion parameters that determine its initial radiation effect are:

— the scaled explosion depth ($\overline{H}$ = H·W$^{1/3}$). At the depths ≥ 120 m·kt$^{1/3}$, as calculations show, the containment zone is formed, which provides retention of the underground nuclear explosion products in the cavity as it collapse. The spalling zone in this case does not overlap with the fracturing zone;

— the initial geological properties of the plot. It is especially important at explosions of small yield (below 10 kt). The location for the explosion is chosen excluding regions of tectonic cracks that make small angles with the line of least resistance (LLR)(slant range)= $\overline{H}$, and of horizontal cracks (along tunnels); and

— the gas pressure in the cavity. For a standard stemming complex, explosion products will not reach the portal tunnel, if severe damage to the stemming at the stage of its deceleration does not take place after the compression wave passes it (time ≤ 0.1-0.5 s) or it is ejected under the action of quasi-static pressure of explosion products (time ≥ 0.5 s) in the cavity. At tests of charges yield < 10 kt TNT equivalent, the advance collapse of the tunnel before the moment of destruction of the stemming face plays the leading and positive role in providing stemming stability.

Radiation criteria

(1) Absence of residual radioactive contamination of the surface of the test site area.

(2) Explosion effects not exceeding the level of natural radiation background variation (except radon exhalation) at the boundary of the 12-mile zone from the Novaya Zemlya coast.

(3) Guaranteed absence of additional radiation effects on the population and ecosystem of regions adjacent to the test site.

(4) Radionuclide activity due to underground nuclear explosions not exceeding 0.1% of the activity of the radionuclides produced at nuclear power stations in the country during a set period, e.g. one year.

The first criterion excludes releases of the aerosol component at an underground nuclear explosion, and of radioactive noble gases (RNG) in amounts that would create noticeable additional effects on fluctuations of the natural background due to depositions of daughter products of RNG decay to the earth`s surface.

The second criterion is based on the use of the factor of meteorological (atmospheric) dilution of RNG. Table XIII gives an example of such an approach, where RNG concentration is given for a uniformly release of 10^6 Ci($3.7 \cdot 10^{16}$ Bq) of RNG in 24 hours.

TABLE XIII. MINIMUM FACTORS OF METEOROLOGICAL DILUTION OF RNG FOR WEATHER CONDITIONS OF THE C CATEGORY (WIND VELOCITY 5 m/s)

Distance, km	10	30	100	200
Dilution factor, m^3/s	$5 \cdot 10^6$	$15 \cdot 10^6$	$5 \cdot 10^7$	$5 \cdot 10^8$
RNG concentration, Ci/l	$2 \cdot 10^{-9}$	$6 \cdot 10^{-10}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$

The third criterion can be provided for a specific equivalent of an underground nuclear explosion by the select of corresponding human conditions, gas content in rock, depth of the charge emplacement, and weather conditions. This guarantees that the natural background variations in the nearest settlements will not be exceeded, and that population exposure will be within the existing standards. For illustration, if it is assumed that xenon-135 concentration in the air of $5 \cdot 10^{-11}$ Ci/l creates the dose rate in the air of 10 μR/hour, the effective, equivalent, individual and collective human doses will not exceed 0.1% of the annual dose from the natural background. This means that the individual risk will be $1.0 \cdot 10^{-8}$, which is by 10^3 times less than the risk from the natural background and is comparable with the risk (frequency) from natural disasters.

The fourth criterion compares the values of activities injected into the eco(geo)sphere at an underground nuclear explosion and during NPP operation. Table XIV shows the activity of the products of a nuclear explosion 100 kt yield as of fission and their concentration in the solidified melt (1000 t /kt).

TABLE XIV. TOTAL ACTIVITY OF UNE PRODUCTS AND THEIR CONCENTRATION IN THE SOLIDIFIED ROCK MELT FOR AN EXPLOSION 100 KT YIELD AS OF FISSION

Time after explosion, years	1	10	50	100	200	400
Activity, Ci	10^6	$5.5 \cdot 10^4$	$2 \cdot 10^4$	$6 \cdot 10^3$	750	200
Melt specific activity, Ci/g	$1 \cdot 10^{-5}$	$5.5 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$7.5 \cdot 10^{-9}$	-

100 years after an underground nuclear explosion, the concentration of radionuclides (mainly fission products) in the rock (melt) is close to the specific activity of 1% uranium ore ($2 \cdot 10^{-8}$ Ci/g), and at shorter times it is close to the activity of low- and medium-activity wastes. In one year underground nuclear explosions with a total TNT equivalent of 1 Mt (as of fission) produces no more than 10^7 Ci of radionuclides at a depth of 400 m and more in the melt with a level of leaching not greater than 10^{-5} g/cm^2 ·per day. An NPP with the power of 1 GW (electricity) will produce 460 kg of fission products with the activity of 10^7 Ci in one year. The actual power of all NPPs in the country is equal to 100 GW (electricity). This means that these NPPs will produce 46 t of fission products and 8.5 t of plutonium with a total activity 10^9 Ci in one year. Therefore, the fraction of radionuclides left after underground nuclear tests with the indicated total yield will be ≤ 0.1% from all NPP fission products.

When the charge emplacement is selected, parameters of the rock are taken into account from the viewpoint of providing minimum leaching of radionuclides after the explosion into underground waters, if they enter the zone of solidified melt. In conditions of the North Test Site, this zone is inaccessible to water. Moreover, there the following factors prevent contamination of the environment:

— low initial concentration of fission products (10^{-5} Ci/g a year after the underground nuclear explosion) and of plutonium (10^{-8} Ci/g);

— low leaching rate (10^{-5} - 10^{-7} g/cm^2·day), i. e. the equilibrium concentration of the fission products in water is ~ 10^{-5} Ci/l in the initial period;

— great migration length and low migration velocity related to a great explosion depth ;

— sorption of the majority of radionuclides by geochemical barriers on the migration path.

This combination of these factors leads to the conclusion that, even in the case of water access, radionuclide concentration in water will be below the permissible levels.

Seismic criteria

The safety criteria are:

— the seismic intensity 3 balls (on Richter scale) is not exceeded. This level cannot be felt by the majority of people in any settlement outside the test site; and

— additional seismic action of all underground nuclear explosions in a year must not exceed 1% in the number and energy release of earthquakes.

Table XV presents the average frequency of earthquakes and their energy on the whole globe ($\lg E = 11.8 + 1.5M$, where energy release is in erg, and M is the magnitude). It is known that at an underground nuclear explosion, no more than 5% of the total energy is released in the form of elastic energy. Therefore, with a total energy release of three–four tests of the greatest permitted energy release (150 kt each) of 500 kt at the North Test Site, the total energy release in the form of elastic vibrations will be 25 kt. This value corresponds to approximately $5{\cdot}10^4$ earthquakes per year. As a result, the effect of underground nuclear explosions will be 0.6% in number, and 0.05% in energy (500 kt/10^6 kt).

TABLE XV. PARAMETERS OF NATURAL EARTHQUAKES FOR THE TERRESTRIAL GLOBE

Magnitude, M	8	7.9-7	6.9-6	5.9-5	4.9-4	3.9-3
Frequency, year^{-1}	1	13	108	800	6200	49000
Energy release, kt	$3.27{\cdot}10^4$	$2.84{\cdot}10^4$	262	191	48	12

Chemical criteria

(1) Concentration of potentially dangerous gases in the atmosphere must not exceed the permissible levels for working premises at the boundary of the 12-mile zone.

(2) Concentration of chemically dangerous substances must not exceed the permissible levels for population in settlements of the regions adjacent to the test site.

(3) Concentration of chemically dangerous substances in the solidified melt of the rock must not exceed their percentage abundance in the earth's crust more than tenfold.

4.10. ASSESSING EXTERNAL GAMMA AND BETA EXPOSURE OF PARTICIPANTS IN NUCLEAR TESTS IN THE ABSENCE OF INDIVIDUAL DOSIMETRIC MONITORING

N.M. Nadezhina, A.K. Gus`kova

At some air and underground tests, direct participants in the tests (from special risk detachments) happened to be in the high ionizing radiation zone. Such situations were:

— entering the zone of a radioactive cloud (non-standard radiation situation);

— work in the radioactive zone: measurement, monitoring and other work (regular radiation situation); and

— dislocation and passage of groups through the radioactive zone (regular radiation situation).

At our hospital, a group of participants of an underground nuclear test of 1969 on Novaya Zemlya underwent a survey. The participants were "covered" by a radioactive cloud 1–1.5 hours after the beginning of a non-standard radiation situation.

Information (see also section 2 of this issue)

Test A-9 (14.10.69) in an tunnel: approximately 60 minutes after the detonation of the nuclear charge (at $\overline{H}$ *~100 m/kt*$^{1/3}$*), an outbreak of steam and gas mixturewas suddenly vented along a tectonic crack formed in the epicentral zone of the massif. In the cloud, radionuclides of krypton, xenon, iodine, tritium, strontium-89, and caesium-137, -138 were detected. Due to the calm weather conditions, the radioactive products hovered over the technological site, causing an EDR of up to some hundreds of R/hour. A strong, hydrogen sulphide odour was noted.*

While the radioactive cloud (jets of radioactive gas) was present, some people were outdoors, where the radiation level reached 200–250 R/hour, and others were indoors, where the radiation level was 60–80 R/hour. The maximum exposure time was about 35 minutes.

Physical examination showed that the participants subjected to ionizing radiation indoors who then came out of the premises received about 0.4 Sv, and persons who stayed the first minutes outdoors received about 0.6 Sv. No individual dosimetry was performed.

The victims were brought to hospital 7–11 days after exposure to radiation. Many of them complained of headache and nausea on the 2nd–4th day. However, it was difficult to connect these symptoms with radiation exposure only, because the test participants were taken out of the contamination zone by water transport during a storm.

78 persons were examined in hospital. Since the victims were brought to hospital 7–11 days after exposure, the range of criteria and parameters used for diagnostics of acute radiation sickness (ARS) was somewhat limited: The lymphocyte level and an investigation of bone marrow cells could not be applied. Therefore, criteria for diagnosing the impact of ionizing radiation that are applicable later were used: dynamics of the levels of leucocytes, neutrophyls, thrombocytes, and the level of chromosomal aberrations in the lymphocytes of peripheral blood.

In 14 persons, acute radiation sickness (ARS) of the 1st degree (light) was diagnosed. In all these cases the dose level assessed on the basis of biological criteria was somewhat higher than assessed on the basis of physical calculations. In the other 64 victims, ARS did not develop. This investigation was performed by the hospital employees M.D. Brilliant, A.I. Vorobyev, V.A. Ivanov, Ye.K. Pyatkin, G.V. Chernega, A.I. Shorokhov and others.

It should be noted that methods exist that permit determination of the absorbed exposure dose independently of time after the exposure. One of them is the study of tooth enamel by means of electronic paramagnetic resonance. The method is sensitive, and was applied, along with the ones indicated above, to study the cases of overexposure, at a time long after the moment of exposure. The good results can be illustrated by the sample of persons who were exposed to radiation in the mid-1950s at nuclear tests at the Semipalatinsk Test Site; they had ARS and have been observed in hospital till the present. At the time of exposure, the EPR method was not applied for dosimetry on the basis of the tooth enamel. According to clinical criteria, ARS of an average degree was diagnosed. This degree corresponds to an absorbed dose of 2–4 Sv. Investigations within the EPR of the tooth enamel performed 35 years after the exposure to radiation have shown that the absorbed dose was 3,1±0,4 Sv.

Thus, currently, specialists in radiation medicine have sufficiently good methods that permit assessment of the received dose even many years after exposure, in the absence of information of individual physical dosimetry.

4.11. AROUND THE ARCTIC NUCLEAR TEST SITE: RADIOLOGICAL CONSEQUENCES ON ADJACENT TERRITORIES

P.V. Ramzaev

With regard to nuclear weapons test in Novaya Zemlya, two principal issues are of special concern to the northerners: contamination of their territory with radioactive substances and a sense of being doomed to suffer from the radiation doses both already received and anticipated. The latter issue is considered in this paper from the viewpoint of a radiologist.

What does it mean for human health to live under the omen of radiation affliction even where it does not pose a real danger, which can be clearly seen from the example of the Japanese who survived the explosions in Hiroshima and Nagasaki? As part of an expert group from the World Health Organization, in 1976 I conducted a spot examination in Hiroshima of the health of the survivors (hibakusia). Almost all of them had various types of complaints; yet, perhaps the main complaint was the concern about their offspring, who were subjected to unofficial everyday discrimination as being afflicted, doomed, and inferior. And who would want to have anything to do with such people? Only 30 years later, when a higher life expectancy of the explosion survivors and the total lack of congenital diseases in their children became known, the fear of radiation began to subside. Being opposed to nuclear weapons, Japan decisively turned its attention to nuclear power generation: 28% of electric power is generated by nuclear power while in the USSR this figure reaches only 12%. Japan maintains this proportion despite the said outcome of the Chernobyl nuclear power plant catastrophe.

The enormous stress experienced today by millions of people in zones with elevated radiation due to the Chernobyl accident and in a number of other regions in the country may lead to an increase in real incidence of disease. It primarily appears due to damage in the neuropsychic system even at such doses which in themselves are negligible, and even with a virtual absence of human-caused exposure.

The international commission, which observed millions of people, has established that annual doses for the entire body of 0.1 Sv or less ensure that there will be no explicit radiation injury, i.e. deterministic threshold injury. And indeed, these injuries could not be identified in the Chernobyl zone by 200 scientists from 25 countries who worked there in 1989–1990 at the request of our country under the auspices of the IAEA and the International Consultative Committee.

Nevertheless, world science is firmly taking the position that there is no threshold effect of radiation, assuming that even minimal doses of irradiation may stimulate cancer and leukemia and cause congenital injuries. This concept persists despite the lack of definitive proof at doses below 0.1–1 Sv. According to the ICRP, a person receiving a 10 mSv dose may lose approximately 4–5 days out of the 25 000 days of his average life. There is a much greater danger to people from not feeling well even without any regard to exposure, e.g. when being forced to relocate. In our estimate, this situation results in a loss of an average of 8 years of full life in almost one quarter of the population. This is why sound and timely information for people about the actual radiation environment in the country, including the Far North where more than two million people live, is becoming increasingly important today.

This is especially important since in recent years, a sizable group of researchers who never before studied the problem of radiation safety began appearing in mass media with statements on the issues of radiation environment in the Far North. They discuss this complicated problem with an enormous almost century-old world scientific basis, so briskly that one sometimes wonders about their boldness. In particular, they also include references to data from our institute. Russia`s leadership is receiving data on the radiation contamination of foodstuffs in the Far North in the form of “alpha or beta particles per1 cm^2 per min ”, while 0.1 of the background is declared as being minimum safe public health standards (upon the personal initiative of amateur dosimetry experts). Radioactive contamination in the Far Northern regions, which, by the way, is lower than that in Moscow by twofold with regard to the ^{137}Cs and ^{90}Sr fallout level is being wholly attributed, needless to say, to the nuclear explosions in Novaya Zemlya while the results of this contamination are seen in almost one-half of the incidents of cancer among the local population (according to data received not by medical institutions but as hearsay from representatives of collective reindeer farms). I am deliberately not citing the names of the authors of these speculations so as not to fight personal battles with them and am hopeful that in time, their level of knowledge will increase as will their scrupulousness. Thus, the question of ″And who are the judges?” is always a legitimate one.

I have had the privilege for the past 30 years, together with my colleagues from the St.Petersburg Institute for Radiation Hygiene (Troitskaya M.N., Miretskiy G.I., Ibatulin M.S. et al), starting with large-scale tests in Novaya Zemlya in open media, continuously and independently from the military forces, of monitoring the radiation environment from Chukotka to the Kola Peninsula. During this period, we took many thousands of measurements of samples from external environmental entities and of human tissue, discharges, and secretion material from the human body. Also, we carried out an analysis of the effect of radiation on reindeer and on the health of the northerners: we conducted numerous experiments on thousands of rodents. The results of these investigations have been recognized by scientists from other Nordic countries, and are being used in official UNSCEAR reports. All this gives us grounds to state in this paper the truth about the ‘nuclear glow’ of the North, which has often been classified in the past.

At the end of the fifties and the beginning of the sixties, the institute, and the radiation-hygiene network of the country, recorded an unusually high concentration of ^{137}Cs and ^{90}Sr in single samples of reindeer meat (from Komi Autonomous Soviet Socialist republic, from Kamchatka, and Sakhalin), which exceeded standards for cattle meat by tens of times. Since at that time nuclear weapon tests were being conducted in Novaya Zemlya, we directly attributed (as did US scientists based on samples taken in Alaska) this venison contamination to these tests. Measurements taken with the help of total body counts of reindeer herdsmen sent to Leningrad from various regions of the North in 1963 demonstrated that ^{137}Cs concentration in their bodies was almost 10–30 times higher than in people who did not consume venison. However, this content was below the permissible standard. Only in one case in 1965, where a maximum fallout was recorded, did we determine a ^{137}Cs concentration of almost $1.8 \cdot 10^5$ Bq, versus a permissible standard in the population of $1.1 \cdot 10^5$ Bq (5 mSv/yr for the whole body).

Needless to say, these data caused serious concern among us. They were reported to all local and central authorities. In addition to the constant political initiatives of our country to ban nuclear weapons, protection measures were extensively developed. It was shown, for example, that venison obtained at the slaughter of animals before their transfer to lichen pastures actually remained virtually clean. When pieces of meat are salted out for 2–3 hours before being eaten, it ensures an additional decontamination by 50–70%. All other food products of northern industries turned out to be virtually clean. And only the use of snow for drinking water during the period of tests in open media was found to be unfavourable.

The radiation environment described above was similar to that in the arctic regions of all countries. Early attempts by me and my colleagues (and also those in America) to attribute all artificial radioactivity discovered there solely to the Novaya Zemlya test site have been totally refuted.

First, all efforts of our institute, of the network of radiation-sanitary control, and of the State Committee for Hydrometeorology of the USSR, to detect in any region of the Soviet coast of the Arctic ocean, convincing evidence of the presence of local radioactive traces from explosions in Novaya Zemlya did not succeed. Even the measurements which we performed by means of aerial gamma survey immediately after the explosions of bombs of extremely high yield without skipping any regions on the northern coast resulted in a universal gamma background level of 5–25 μR/h, which corresponds to natural radiation. This is due to the fact that the tests in Novaya Zemlya were carried out primarily in the bombing mode, in which radioactive products enter the stratosphere, and add to the products of tests at other test sites, including those in other countries. During all ensuing monitoring years, these values did not change. As a result of our recent measurements taken in October 1991, we did not detect any new areas of artificial radioactive contamination due to nuclear explosions.

Second, in the most loaded" chain, "lichen–reindeer–human, variations in the radioactivity levels from region to region are due not to the distance from Novaya Zemlya, but to the amount of atmospheric precipitation. In this case, the mechanism by which ^{137}Cs and ^{90}Sr enter precipitation and appear in lichen is due to the radioactive gas behaviour of xenon and krypton. During the explosion, they rise to the stratosphere (above 10km), where strong winds rotate them in the northern hemisphere, mixing them with other radionuclides (and their daughters nuclides ^{137}Cs and ^{90}Sr) from all other explosions in other countries whose test sites are located in the northern hemisphere. It is virtually impossible to distinguish these radionuclides according to their origin, e.g. whether they are Soviet or American, when they are already present in the body of reindeer or a reindeer herdsmen. Only their division in proportion to the yield of the explosions conducted due to the fission of heavy nuclei can be tentatively attributed to a certain extent to the proportion of radioactive nuclides of local origin.

At the same time, we should note that physically, half as much radioactive precipitation fell in the Far North per unit of territory than, for example, at the latitude of Moscow. Nevertheless, it turned out that the indigenous northern inhabitants were exposed to a higher effect of ^{137}Cs and other radionuclides tens of times higher than Moscowites. There is no mistake here: the secret is in the characteristic features of flora and fauna of the region, namely lichens and their forage importance in the North. Lichen has enormous (as compared to grass) sorption surface per unit of mass which, in the form of microscopic fungus filaments, is completely open to radioactive precipitation. Lichen lives for decades, and all this time accumulates both ^{137}Cs and ^{90}Sr and, which is especially unfavourable, such natural radionuclides as lead-210 and polonium-210. It does not have roots. Nevertheless, it 'sucks' radionuclides from the soil ten times more efficiently than grass but these nuclides are 'washed off' more slowly by almost fivefold. Lichen in Moscow, for example, is twice as radioactive as beyond the arctic circle, yet in moderate latitude it does not have any animal feed value.

After cessation of atmospheric tests in the northern hemisphere (since 1963), and the ensuing years, since winter 1965–1966, the concentration levels of artificial long-lived radionuclides, and consequently, the exposure doses of the Far North inhabitants began to decrease, and now they have decreased by tenfold. This cleansing began among the population in moderate latitudes one year earlier and proceeded faster. On average, during the last 30 years, the reindeer herdsmen and members of their families whose daily venison consumption for the entire north according to our data is 250g (equivalent of muscle tissue), received an additional average effective dose of 1 mSv/yr (in 30 years- 30 mSv).

The second addition, also 1 mSv/year, to the usual dose of a USSR inhabitant (4.2 mSv/year) is due to ^{210}Pb and ^{210}Po. Yet these are natural radionuclides; their content does not depend on explosions. They existed long before the onset of the atomic age. Thus, reindeer herdsmen and members of their families whose population amounts to approximately100 000 people, compared with people who do not consume venison, received in the past 30 years an additional dose compared to the average exposure dose for the country (0.13 Sv), making 60 mSv.

According to the risk factors calculated for 100 000 persons and published by ICRP in 1990, receiving a 60 mSv dose may lead to the appearance of tumours and genetic defects in 440 people with an average decrease in life of 15 years, yet that due to nuclear tests in open media alone in 220 people. We know that under normal conditions (without additional radiation) the death rate from cancer for100 000 people is 20–10 000persons, so an addition of 1% against the background of fluctuations (50%) cannot be recorded virtually by any science.

Nevertheless, despite this arithmetic, researchers from the Institute for Radiation Hygiene conducted consistent monitoring of the health of the northern residents and recorded their mortality from oncological diseases and sought to establish a correlation with the aforesaid exposure doses. It turned out that despite expectations, that cancer mortality is inversely proportionate from the dose level created by ^{137}Cs. Among the indigenous inhabitants of the Kola Peninsula the dose levels are almost five times higher than among tundra residents in the Yakutia, while the mortality from cancer of the oesophagus (which is in the north is higher by 15—20 among the population of temperate latitudes) is highest among Yakyts, and lower among the residents of Murmansk. Yet the mortality from cancer turns out to be closely correlated to the severity of the climate and, according to our version (which is still to be proven), with the consumption of hot beverages.

We also observe a similar phenomenon in a number of areas in Central Asia, where cancer of the oesophagus is also a consequence of drinking hot beverages. It should be noted that inhabitants of the north have a short life expectancy — 40–45 years, on average — whereas nationwide it is about 70 years. In the North, there are a lot of various negative factors, which should be studied and corrected. If we continue to blame radiation, we ignore other important factors that influence health. I would like to warn against this. However, if we speak about countermeasures, I ask the Government to pay special attention to the critical group of reindeer herdsmen and members of their families, about 100 000 people. These are the main results of the studies of radioactivity impact in the Far North.

All the radioactive problems that we face now come from the time when nuclear explosions were detonated in open media. Underground explosions have not contributed to environmental contamination. Measurements even on Novaya Zemlya itself in summer 1991 (from Vaygach island to Matochkin Shar straits) demonstrate that radiation levels there corresponded to the natural background. Only in several small areas with diameters of 0.5–1 km at the places of former explosion epicentres, can one record on the order of 100 μR/h (according to E.Ya.Ostrovskiy measurements). On the rest of the Novaya Zemlya territory, only the natural background is picked up. Claims which describe Novaya Zemlya as highly contaminated territory are characterized by being biased and crowd pleasing. Thousands of servicemen are living there with their families.. These are highly skilled experts and scientists, they have dosimeters and, consequently, are aware of the situation.

My colleagues and I are against nuclear weapons and their tests, which position I have often stated, in particular, in October 1990, when together with a group of scientists (Trutnev Yu.A., Matushchenko A.M., Tokmachev S.N., Safronov V.G., Dumik V.P. et al), we visited the Yamal territory, where we publicly took mass measurements of radioactivity among the population and radiation in the environment. The maximum level of the ^{137}Cs concentration, which was found in the critical group, was approximately 5% of the permissible level. In my opinion, even these percentages should be eliminated.

At the same time, using the rights of science. I would like to lift the sense of inevitability from the people of the far north due to radiation which has been imposed upon them due to ignorance or misunderstanding. Existing radiation does not pose real danger to their health. From the viewpoint of both international and domestic standards, all locally produced alimentary products are clean. There is no need to take any measures for radiation protection from the bombing radioactivity at the present time anywhere in the territory of Russia′s far north. Today, certain centres of elevated natural radioactivity (especially radon in buildings) and uncontrolled irradiation of the population during medical diagnostic procedures pose the principal radiation danger. Here, collective radiation danger for the entire country can be measured as 300 Chernobyls. We shall deal with this issue on a different occasion.

APPENDIX I
ABBREVIATIONS

CPI – the Complex Programme of Investigations

CCE – (complete contained explosion) an underground explosion of complete internal action accompanied by the formation of an underground cavity with a respective compaction, fragmentation and cracking of rock around it, but the rock pillar prevents the release or seepage of gaseous products

ICE (RNG) – (incomplete contained explosion) an explosion of complete internal action accompanied by jointing of fissured and spalled zones on the earth`s surface in the explosion epicentral area, and by a ventilation, as a rule, insignificant seepage into the atmosphere of short-lived radionuclides of noble gases (RNG)**:**
^{85M}KR ($T_{1/2}$= 4.5 H), ^{87}KR($T_{1/2}$= 76.3 MIN.), ^{88}KR($T_{1/2}$= 2.84 H), ^{131M}XE($T_{1/2}$= 11.9 D), ^{133}XE($T_{1/2}$= 5.2D), ^{133M}XE($T_{1/2}$= 2.2 D), ^{135}XE($T_{1/2}$= 9.9 H), ^{135M}XE($T_{1/2}$= 15.3 MIN.), ^{138}XE($T_{1/2}$=14.17 MIN.)

EEZ – epicentral explosion zone

EDR – exposure dose rate of gamma radiation (μR/h, mR/h, R/h)

EEZ – explosion epicentral zone (epicentre is the point on the ground surface located directly above the charge)

FAO – Food and Agriculture Organization of the United Nations

IAEA –International Atomic Energy Agency

ICRP –International Commission on Radiological Protection

IDEC –Interdepartmental Expert Commission on Assessing the Radiation and Seismic Safety of Underground Nuclear Tests

IGY – the International Geophysical Year

JVE – Joint Verification Experiment (monitoring of a nuclear tests carried out jointly by experts from USA and USSR)

LLR = H_{LLR} – the line of least resistance or slant range (the shortest distance between the charge centre and the ground surface, m)

NB –natural background

NC – nuclear charge

UNSCEAR – t United Nations Scientific Committee on the Effects of Atomic Radiation

NCRP – National Commission on Radiological Protection

NE – nuclear explosion

NPP – nuclear power plant

NRB – () radiation safety standards

NRS – non-standard (accidental) radiation situation (accidental disruption of the regular test conduct process or its consequences unforeseen by the project, which may lead or has led to exposure people above the set standards or material damage)

NT – nuclear test

NTS – Nevada test site

PNE – peaceful nuclear explosion

RNG – radioactive noble gas, containing mainly short-lived radionuclides: krypton-85m ($T_{1/2}$ = 4.5 hour) krypton-87 ($T_{1/2}$ = 76.3 min) krypton-88 ($T_{1/2}$ = 2.84 hour) xenon-131m ($T_{1/2}$ = 11.9 days) xenon-133 ($T_{1/2}$ = 5.2 days) xenon-133m ($T_{1/2}$ = 2.2 days) xenon-135 ($T_{1/2}$ = 9.09 hour) xenon-135m ($T_{1/2}$ = 15.3 min) xenon-138 ($T_{1/2}$ = 14.17 min)

RP – radioactive product

RS – radiation safety

SC – stemming complex

TPL – temporary permissible level (of radioactive contamination)

UNE – underground nuclear explosion

VNIIEF – All-Russia Scientific Research Institute for Experimental Physics (the Russian Federal Nuclear Centre, Arzamas-16)

VNIITF – All-Russia Scientific Research Institute for Technical Physics (the Russian Federal Nuclear Centre, Chelyabinsk-70)

WHO –World Health Organization

APPENDIX II
SYMBOLS FOR VALUES

H – the depth of the nuclear charge location, m;

$\overline{H}$ – the scaled depth of the nuclear charge location, m·kt$^{-1/3}$;

T_0 – the time of beginning of release of radioactive products to the "earth`s" surface (min, hour, day);

$T_{1/2}$ – the radionuclide half-life (sec, min, hour, etc.);

W – yield (explosion energy release) in kilotons (kt) of trinitrotoluene equivalent.

APPENDIX III
RADIATION SAFETY STANDARDS AND RADIATION DOSES FROM IONIZING RADIATION SOURCES

(1) The permissible levels of radioactive contamination established for foodstuffs in international trade and approved by the WHO/FAO commission Codex Alimentarius [1] are as follows: 1000 Bq/kg for ^{131}I and ^{137}Cs, and 100 Bq/kg for ^{90}Sr – in foodstuffs intended for general consumption; 100 Bq/kg for ^{131}I and ^{90}Sr and 1000 Bq/kg for ^{137}Cs – in milk and children's food.

(2) The permissible concentrations in the atmospheric air according to the Soviet standards for radiation safety NRB-76/87 are: for ^{134}Cs – 0.017 Bq/l ($4.4 \cdot 10^{-13}$ Ci/l); for ^{137}Cs – 0.018 Bq/l ($4.9 \cdot 10^{-13}$ Ci/l); ^{90}Sr – 0.0015 Bq/l ($4 \cdot 10^{-14}$ Ci/l); for ^{239}Pu – $1.1 \cdot 10^{-6}$ Bq/l ($3.0 \cdot 10^{-17}$ Ci/l).

(3) The permissible limit of ^{137}Cs intake with food in a human body is $4.4 \cdot 10^{5}$ Bq/year (12 μCi/yr).

(4) Table III.1 presents the temporary permissible concentration levels for ^{137}Cs and ^{90}Sr content in food and drinking water established in the USSR after the Chernobyl accident (TPL-91) in 1991. For comparison, the table gives the actual concentrations of these radionuclides in water and foodstuff samples collected on Novaya Zemlya and in adjacent regions. It is easy to assess that a person must consume several tons of reindeer meat per year to accumulate the annual permissible body content of ^{137}Cs. Actually, the meat consumption is up to 100 kg/yr – according to the data presented in 1990 at a congress on small populations of the North, and up to 600 kg/yr – according to the data of V. Lupandin [2].

TABLE III.1.

Food products etc.	Radionuclide concentration, Bq/kg (Ci/kg)					
	WHO/FAO		TPL–91		Novaya Zemlya and Far North Regions	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Drinking water	1,000 ($2.7 \cdot 10^{-8}$)	100 ($2.7 \cdot 10^{-9}$)	18 ($5 \cdot 10^{-10}$)	4 (10^{-10})	0.04-0.4 $(0.1–1) \cdot 10^{-12}$	0.04-0.4 $(0.1–1) \cdot 10^{-12}$
Milk, sour milk products	1,000 ($2.7 \cdot 10^{-8}$)	100 ($2.7 \cdot 10^{-9}$)	370 (10^{-8})	37 (10^{-9})	0.4- 4 ($10^{-11}–10^{-10}$)	
Meat	1,000 ($2.7 \cdot 10^{-8}$)	100 ($2.7 \cdot 10^{-9}$)	700 ($2 \cdot 10^{-8}$)	700 ($2 \cdot 10^{-8}$)	15-37 ($(0.4–1) \cdot 10^{-9}$)	
Fish	1,000 ($2.7 \cdot 10^{-8}$)	100 ($2.7 \cdot 10^{-9}$)	700 ($2 \cdot 10^{-8}$)	700 ($2 \cdot 10^{-8}$)	11-26 ($(0.3–0.7) \cdot 10^{-9}$)	
Lichen	–	–	–	–	70-300 ($(2–8) \cdot 10^{-9}$)	

(5) According to IAEA data [3], the current worldwide mean annual individual radiation doses due to natural and artificial sources are, in mSv:

natural background (NB) – 2.4;

medical practice (diagnostics) – 1;

professional exposure – 0.002;

production of nuclear energy – 0.0002;

all nuclear tests – 0.01.

(6) For comparative assessment of the effect of environmental exposures on the global population , the following individual and collective doses equivalent to the natural background exposure duration have been accepted [3]:

— One year of present worldwide nuclear power production is equivalent (or is slightly less than) one additional hour of radiation exposure from the NB (excluding the effect of long-lived radionuclides). If the latter radionuclides are included here (mainly, carbon-14), the expected dose is equivalent to approximately 37 hours of additional NB exposure.

— From the Chernobyl accident (i.e. even in the extreme case), the expected dose (received during the next 30 years mainly from caesium-137) is equivalent merely to 21 days only of additional NB exposure.

— From professional exposure – approximately 9 hours of additional NB radiation exposure during a year.

— From medical diagnostics – approximately 1.4–6 months of additional NB radiation exposure.

— All nuclear tests – the expected long-term collective dose is equivalent to 28 months of additional NB exposure.

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